

An EUV Fresnel zoneplate mask-imaging microscope for lithography generations reaching 8 nm

Kenneth A. Goldberg, Iacopo Mochi, James Macdougall,
Nathan S. Smith, Senajith B. Rekawa, Patrick Naulleau

Center for X-Ray Optics
Lawrence Berkeley National Laboratory



The SEMATECH Berkeley Actinic Inspection Tool (AIT)

λ : 13.2–13.6 nm

NA (4x): 0.25–0.35, $\angle 6^\circ$

Mag: 907x

Synchrotron

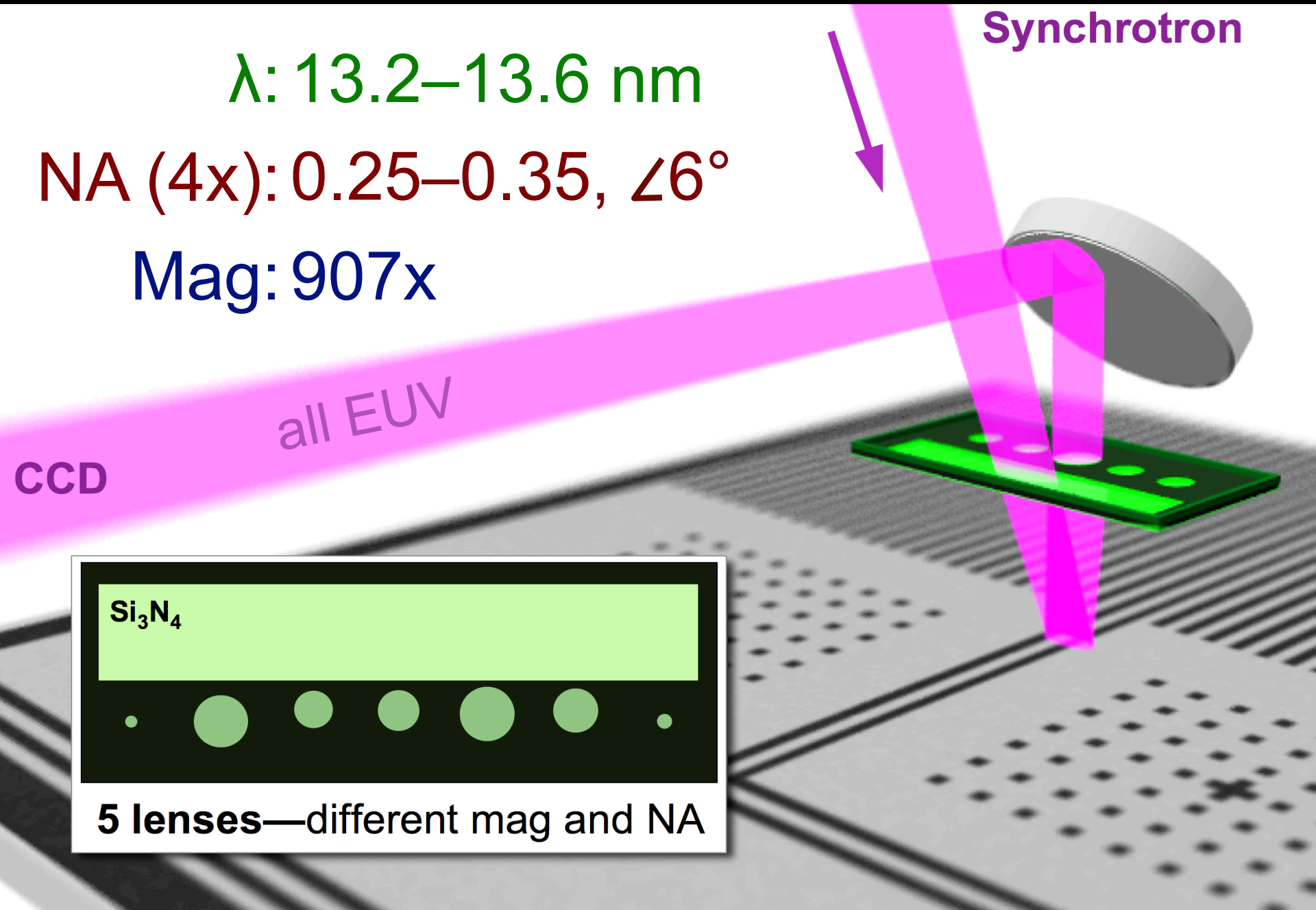
all EUV

CCD

Si_3N_4



5 lenses—different mag and NA



Primary ALT users in 2010/11

CNSE

Mask Contamination
& Cleaning

Intel

Mask Cleaning
Native Pattern Defects

GlobalFoundries

Pattern Bias / OPC

Samsung

Defect Printability

IBM

Programmed
Pattern Defects

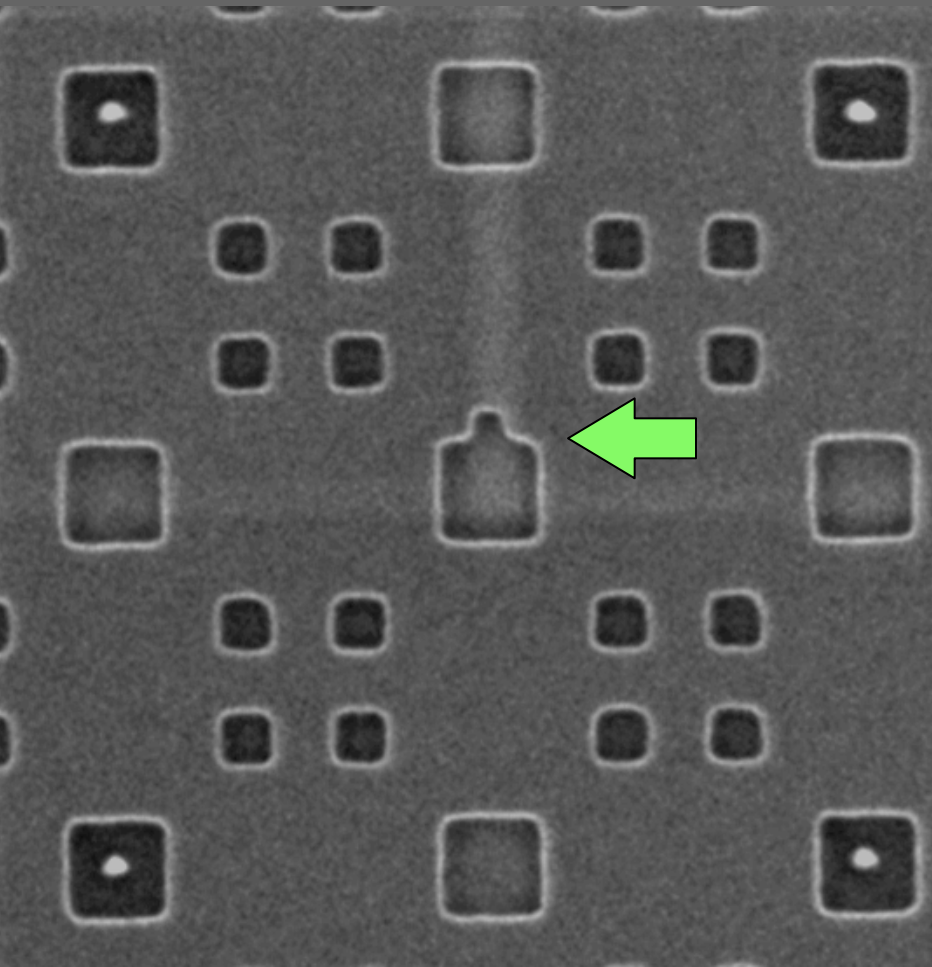
SEMATECH

Native Blank &
Pattern Defects

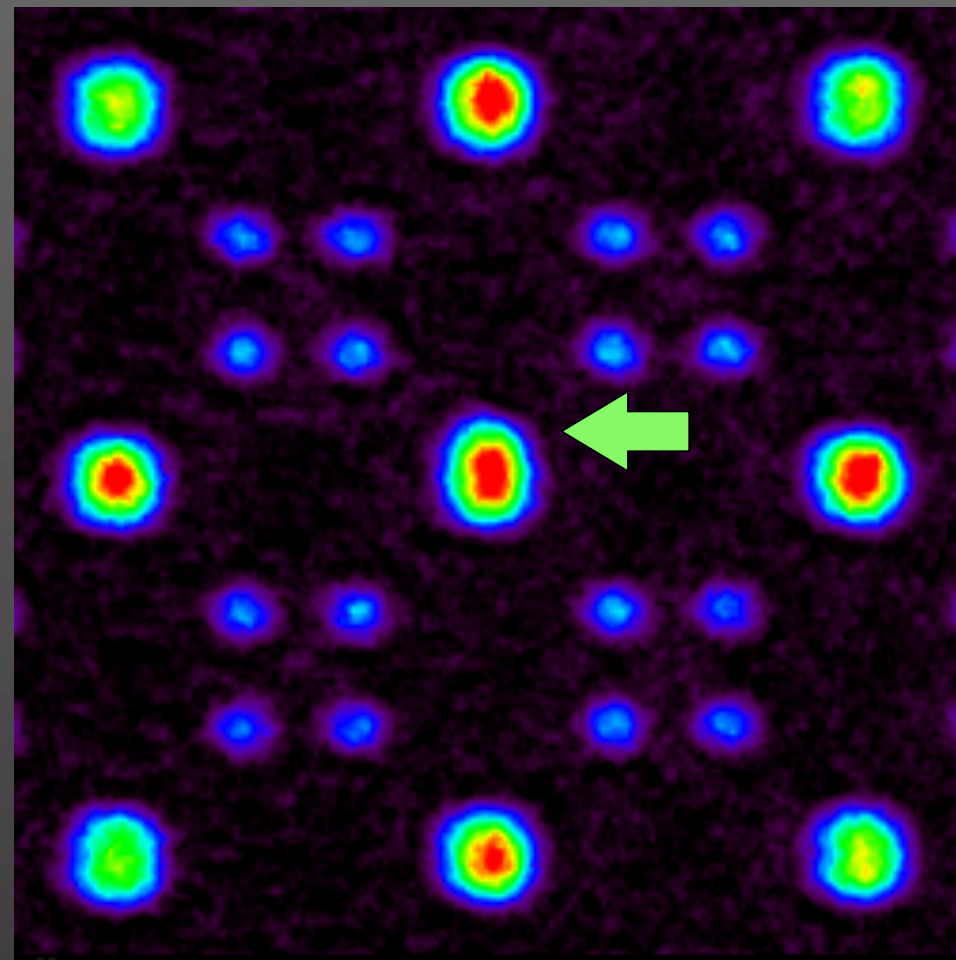
LBNL

Phase Imaging, Performance Optimization

IBM Programmed Pattern Defects



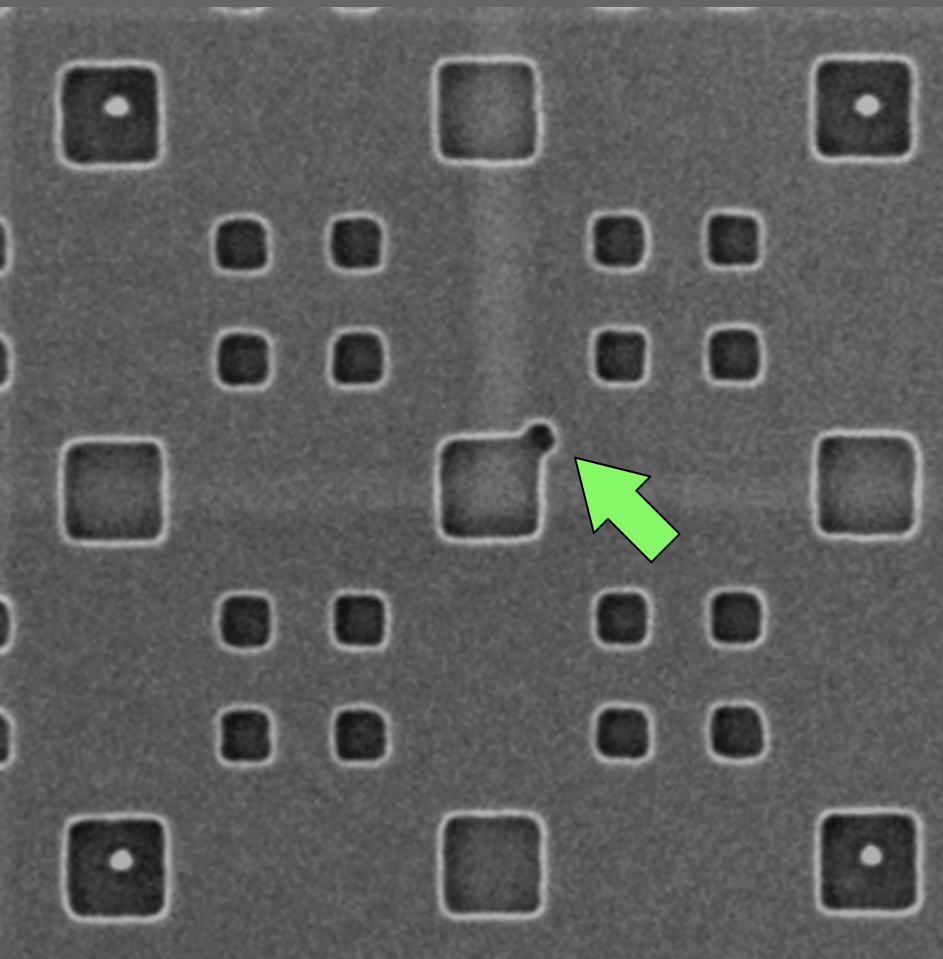
SEM



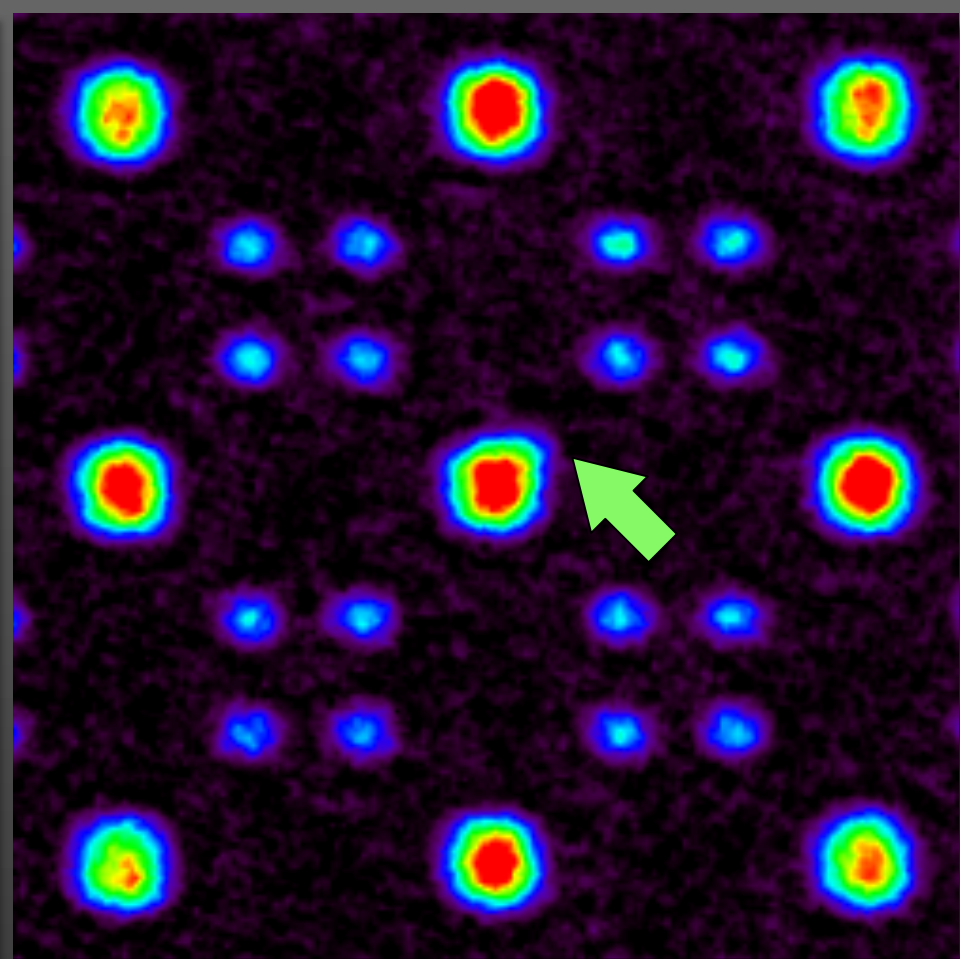
AIT (EUV)

— 500 nm

IBM Programmed Pattern Defects



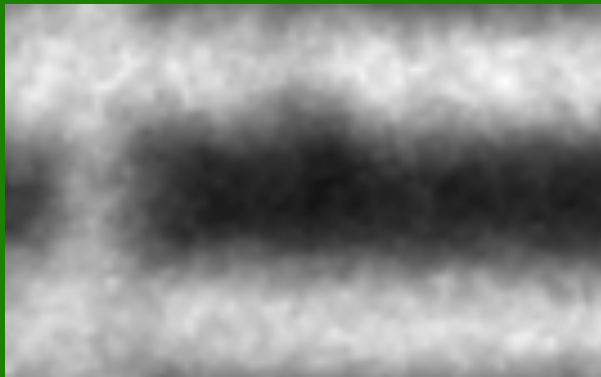
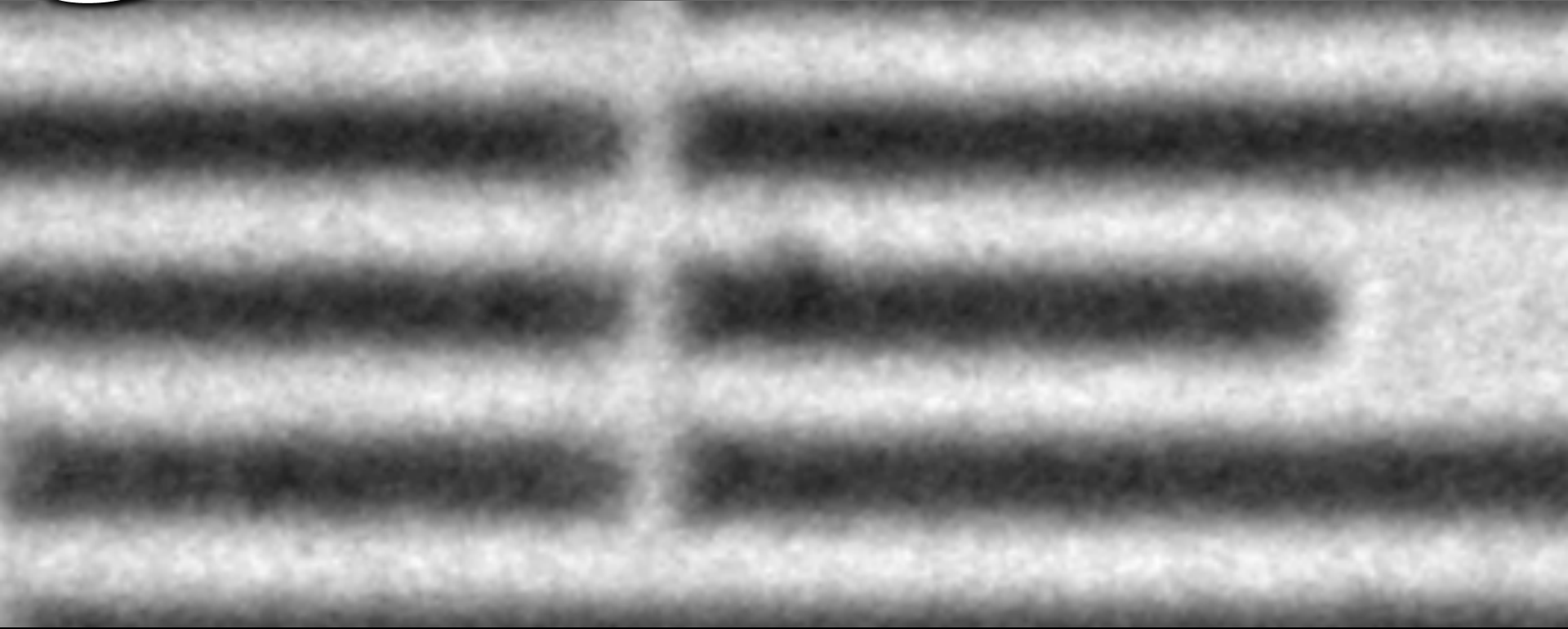
SEM



AIT (EUV)

— 500 nm

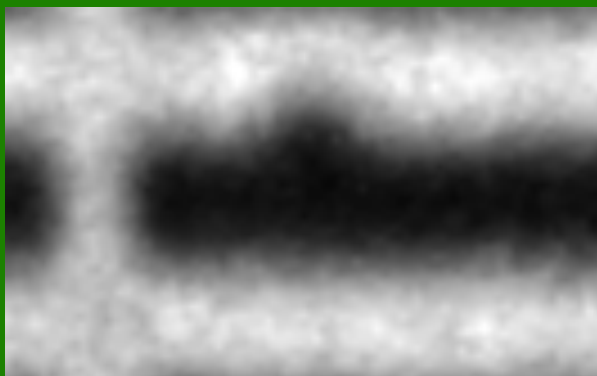
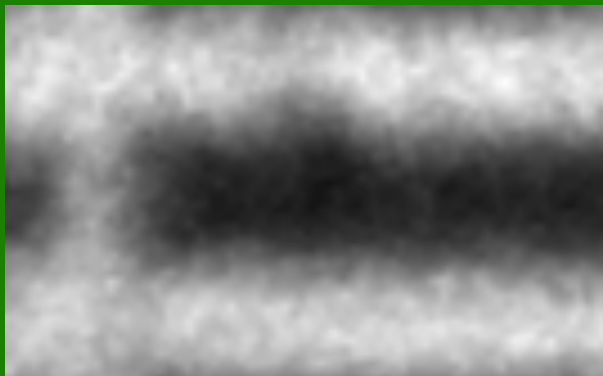
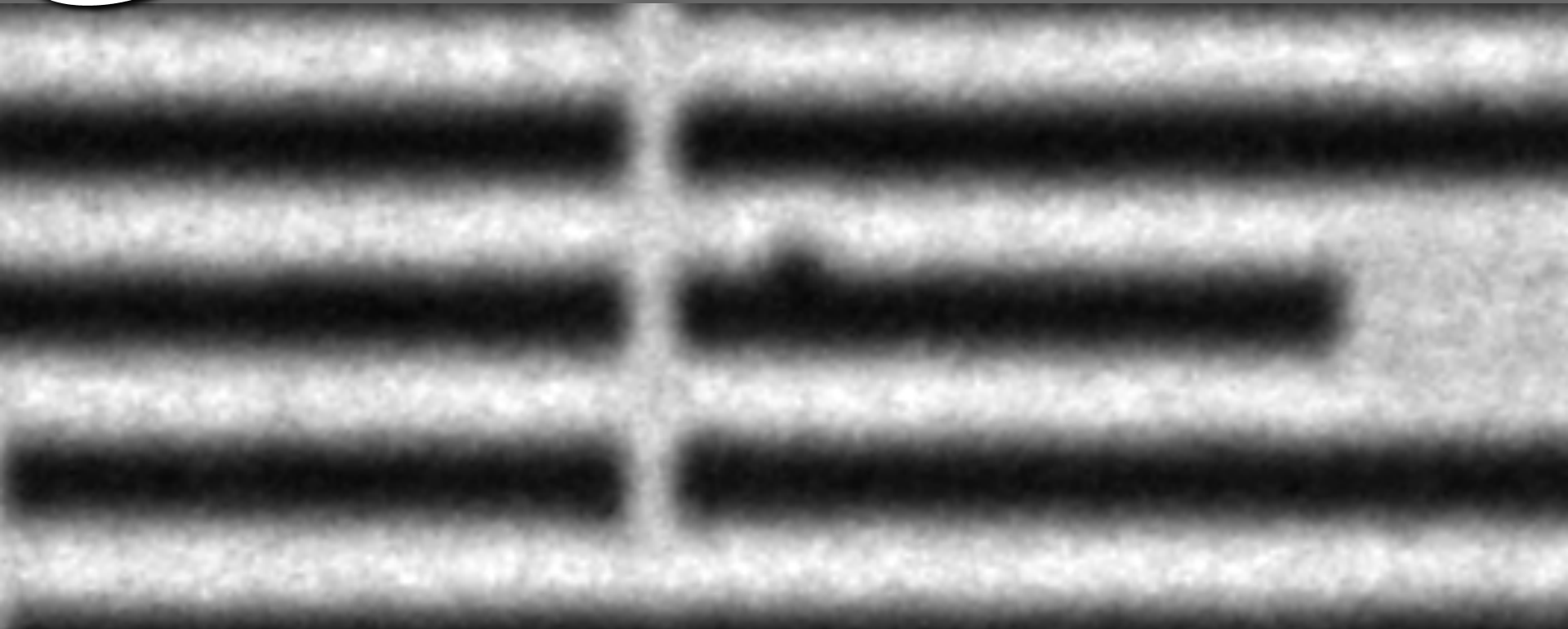
intel® Native Pattern **Amplitude** Defect



Mask: IMO182140 / Magana, *unpublished 2010*

 **500 nm**

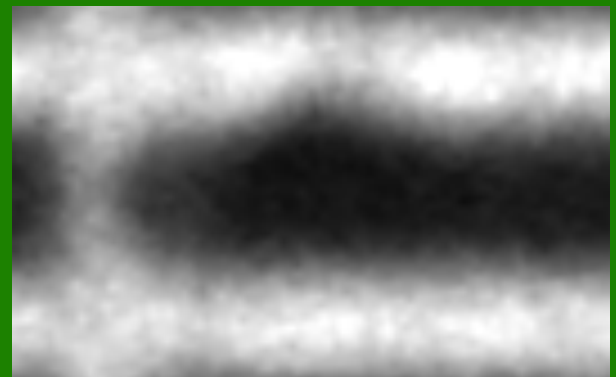
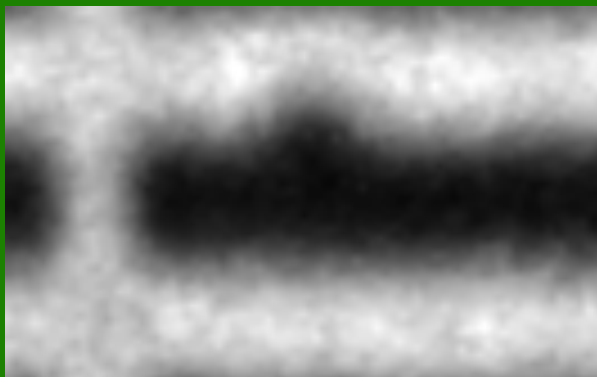
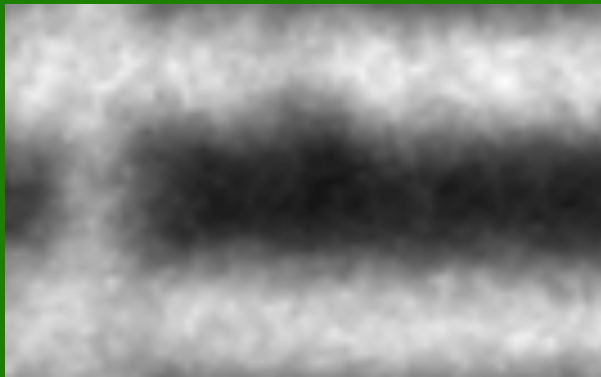
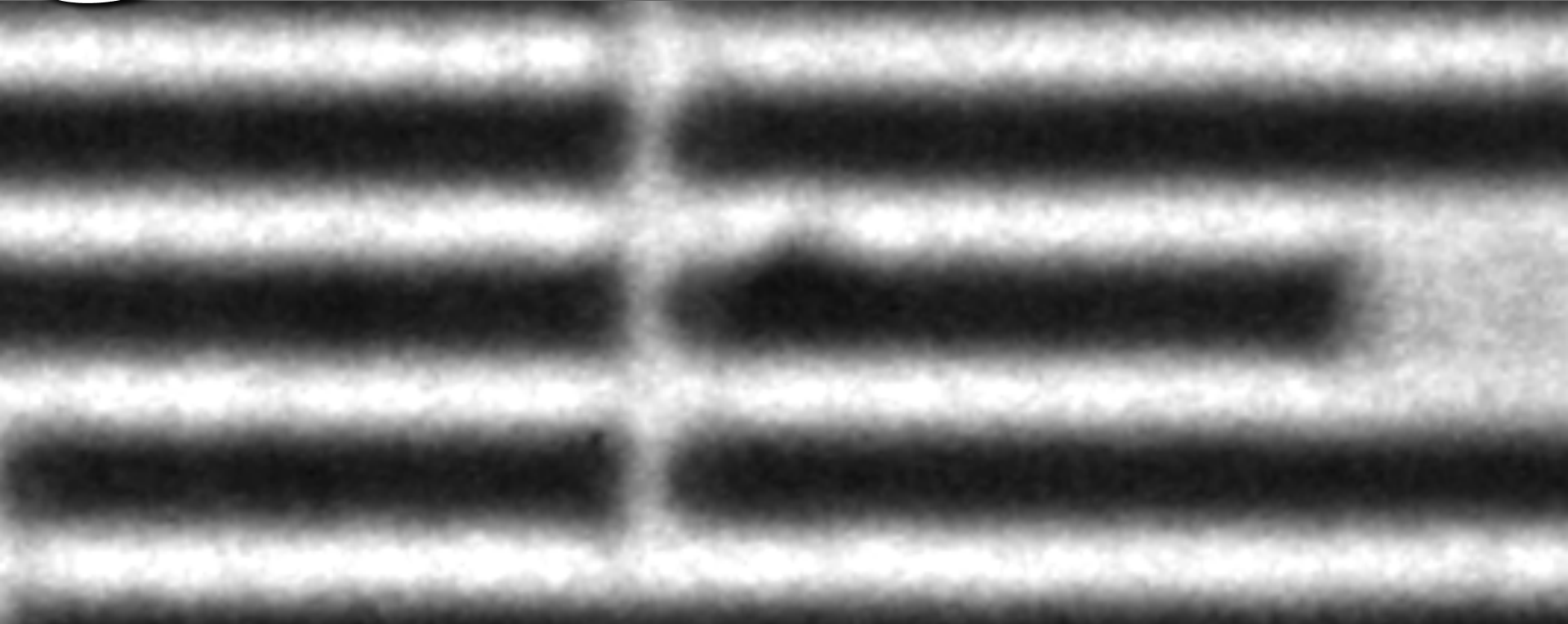
intel® Native Pattern **Amplitude** Defect



Mask: IMO182140 / Magana, *unpublished* 2010

 **500 nm**

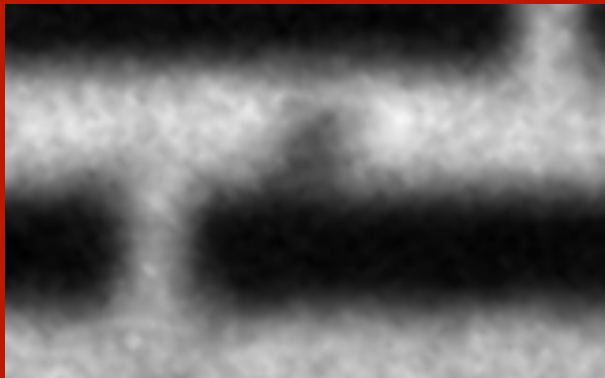
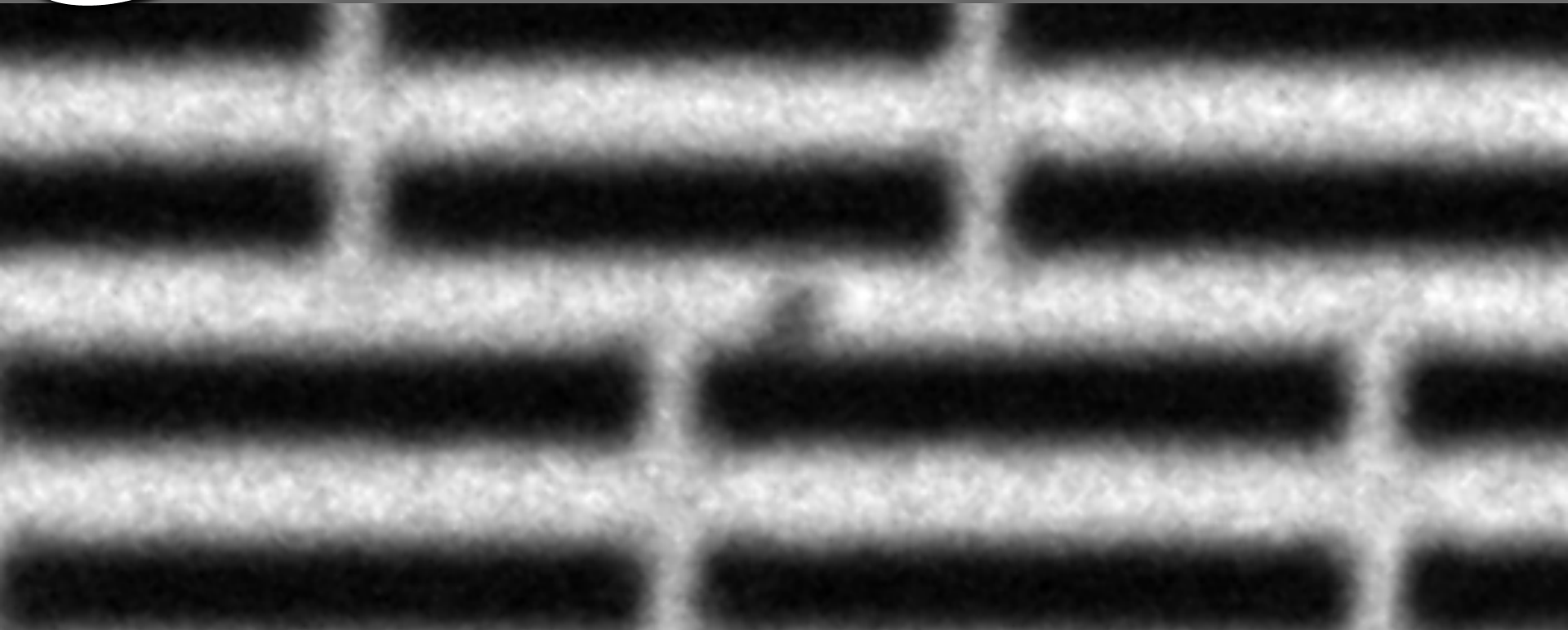
intel® Native Pattern **Amplitude** Defect



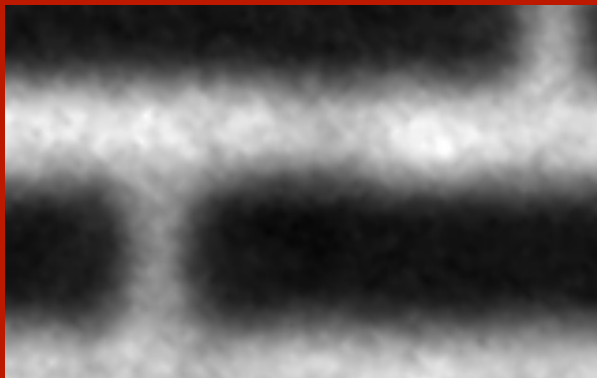
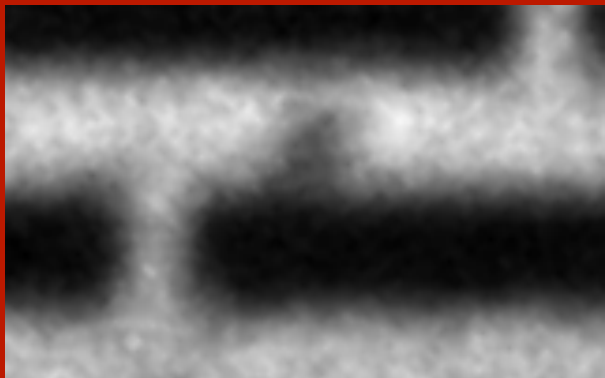
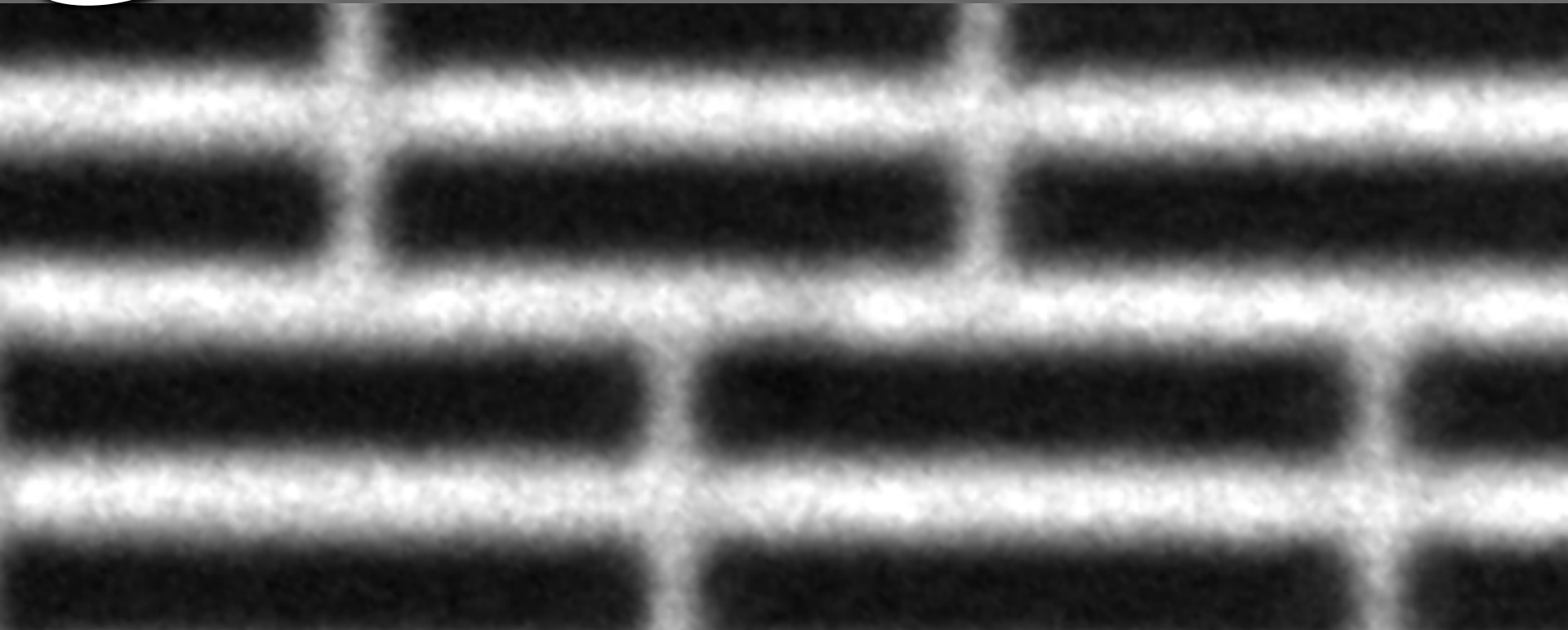
Mask: IMO182140 / Magana, *unpublished* 2010

 **500 nm**

intel® Native Pattern **Phase** Defect



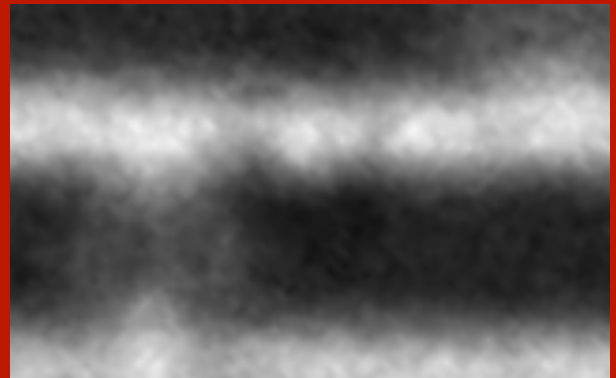
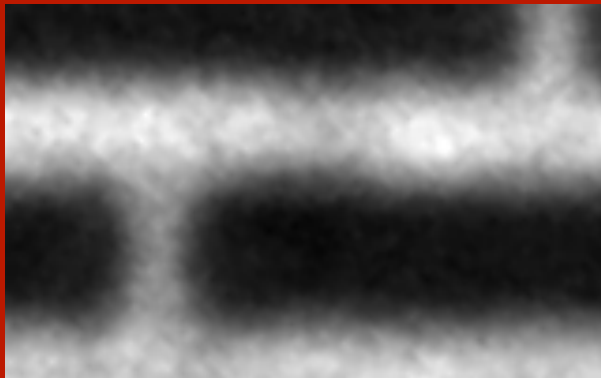
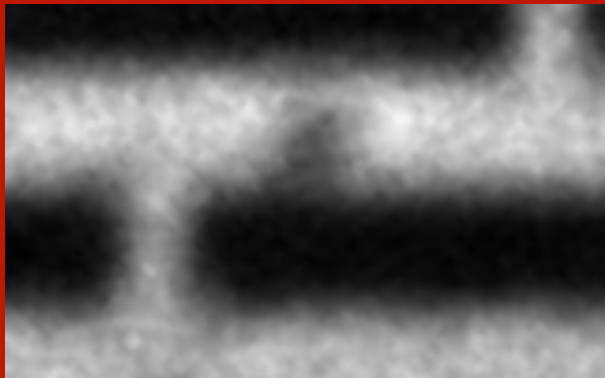
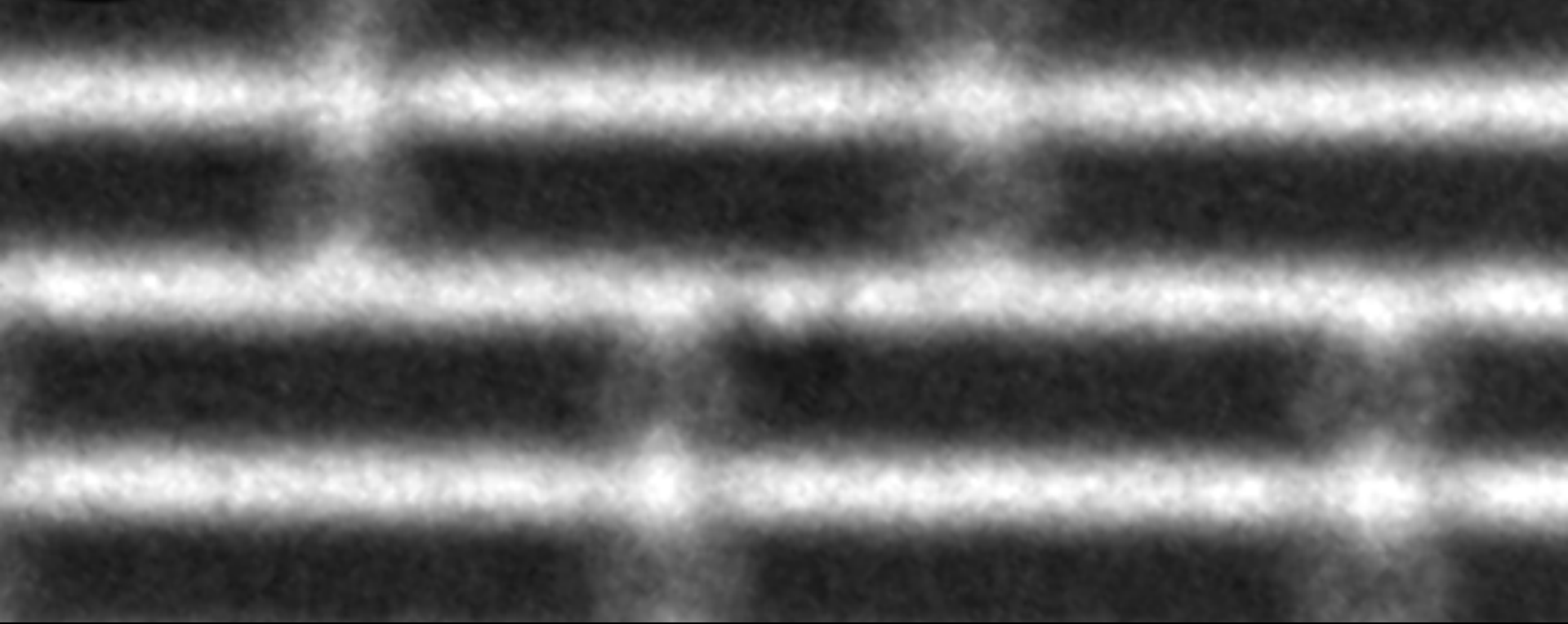
intel® Native Pattern **Phase** Defect



Mask: IMO182140 / Magana, *unpublished* 2010

 **500 nm**

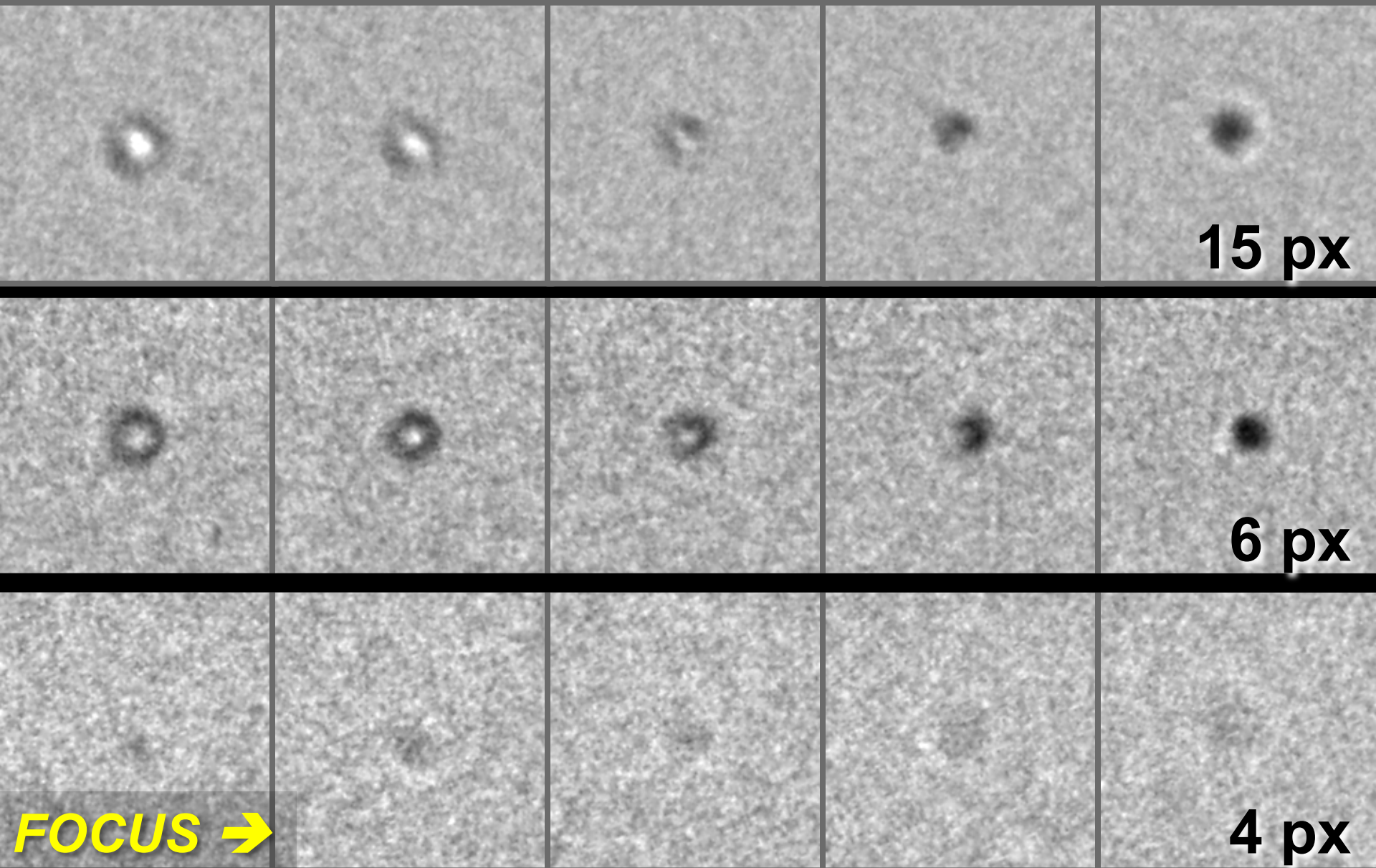
intel Native Pattern **Phase** Defect



Mask: IMO182140 / Magana, *unpublished* 2010

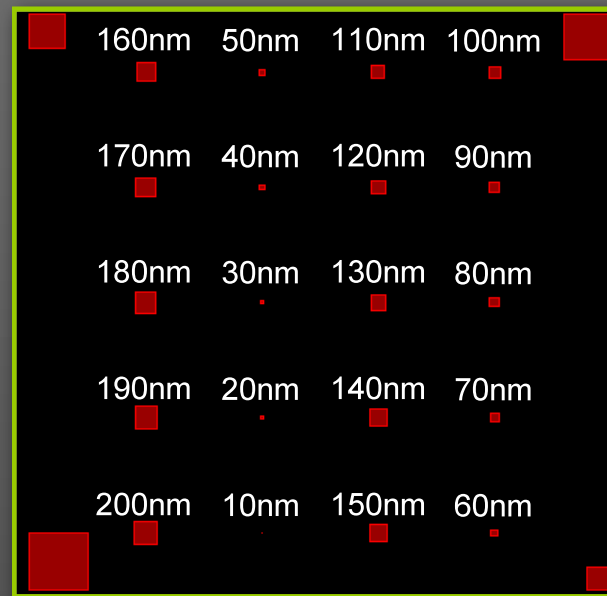
 **500 nm**

SEMATECH Native Mask-Blank Defects

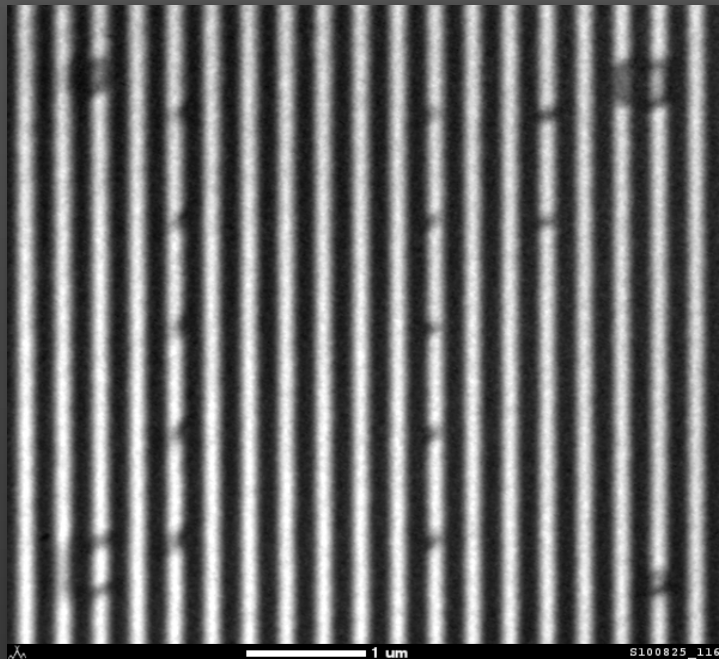


SAMSUNG

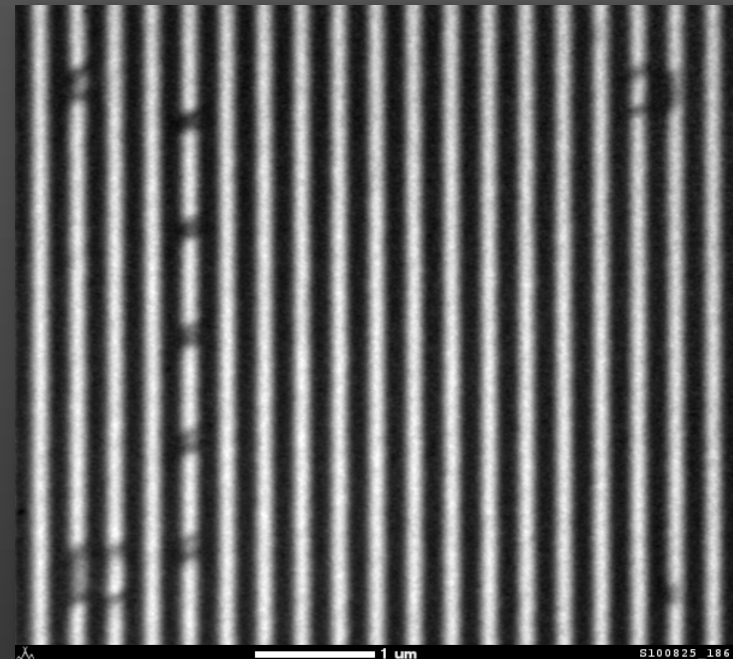
Buried phase defects



ALT Images

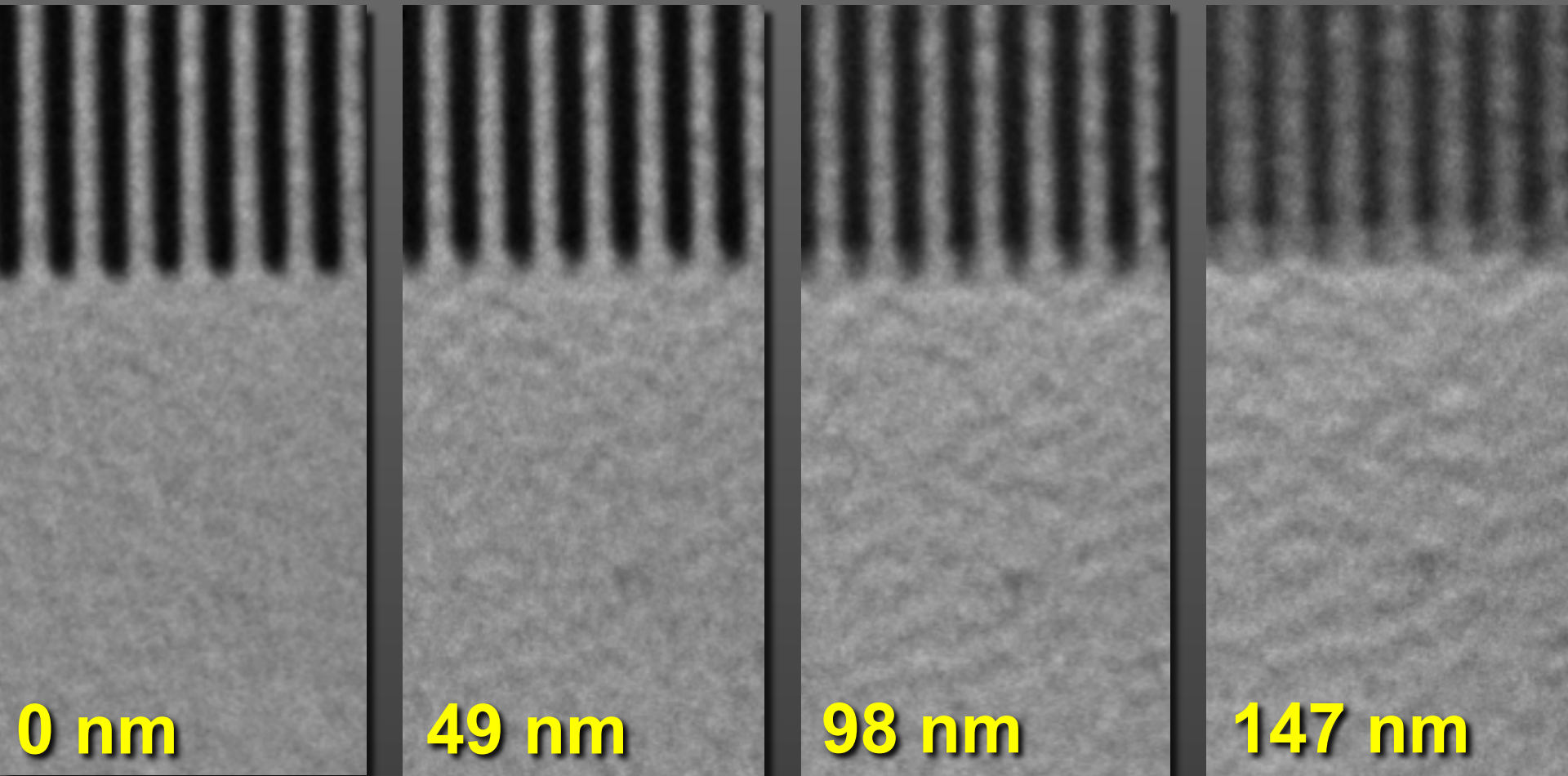


A pattern position shift. . .



covers the defects

Speckle from ML phase roughness



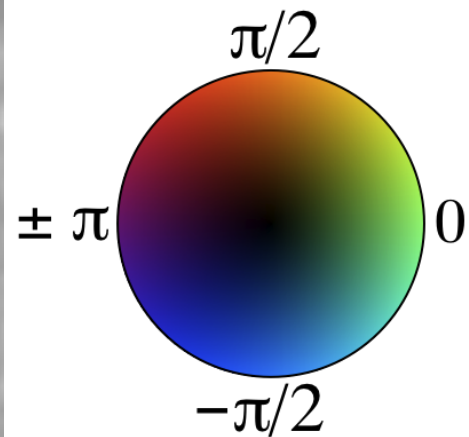
Focus →

CXR

SEMATECH

Goldberg, Mochi, Naulleau, George (2008), *unpublished*

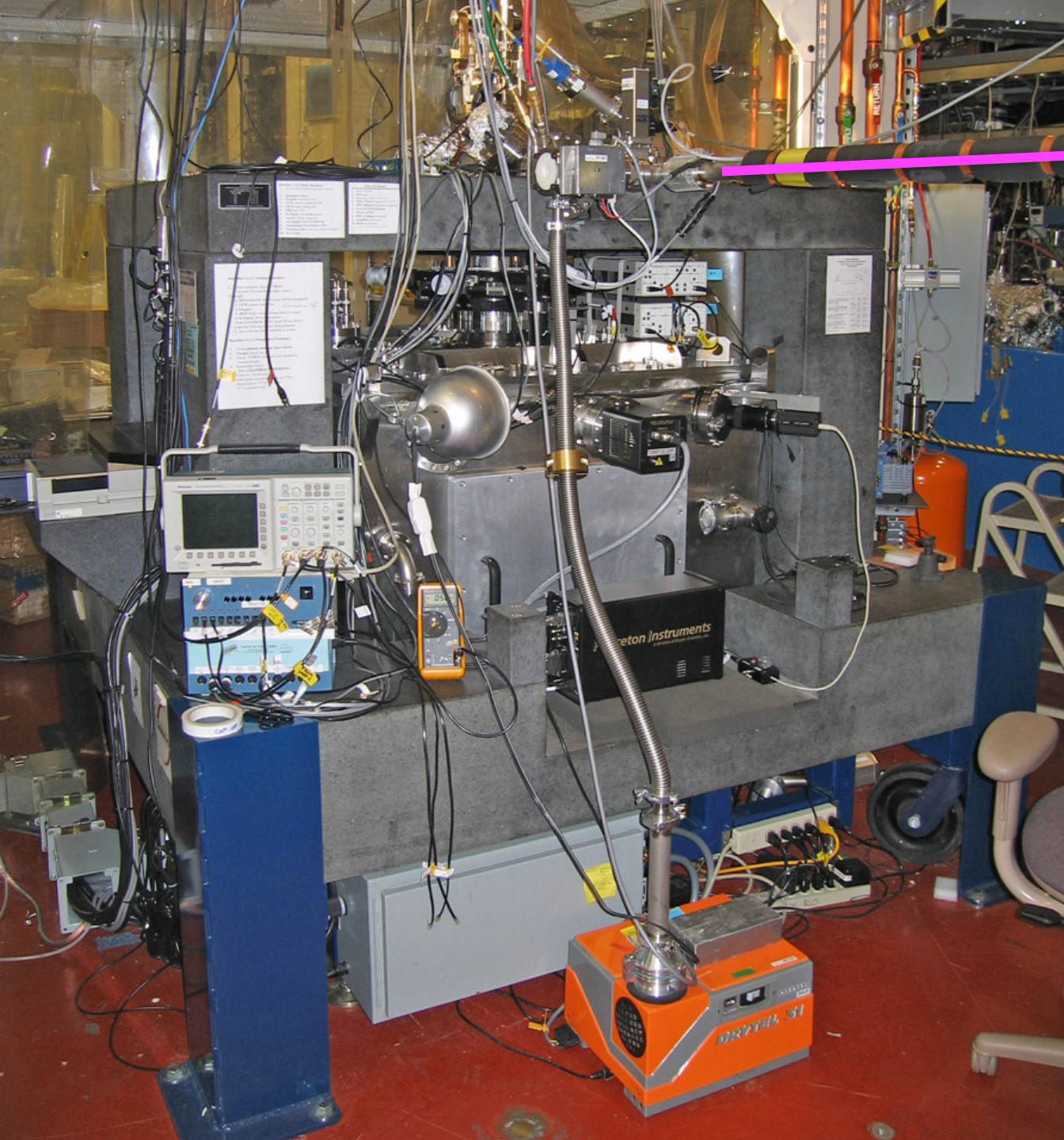
I. Mochi
7969-67



0.5 μm

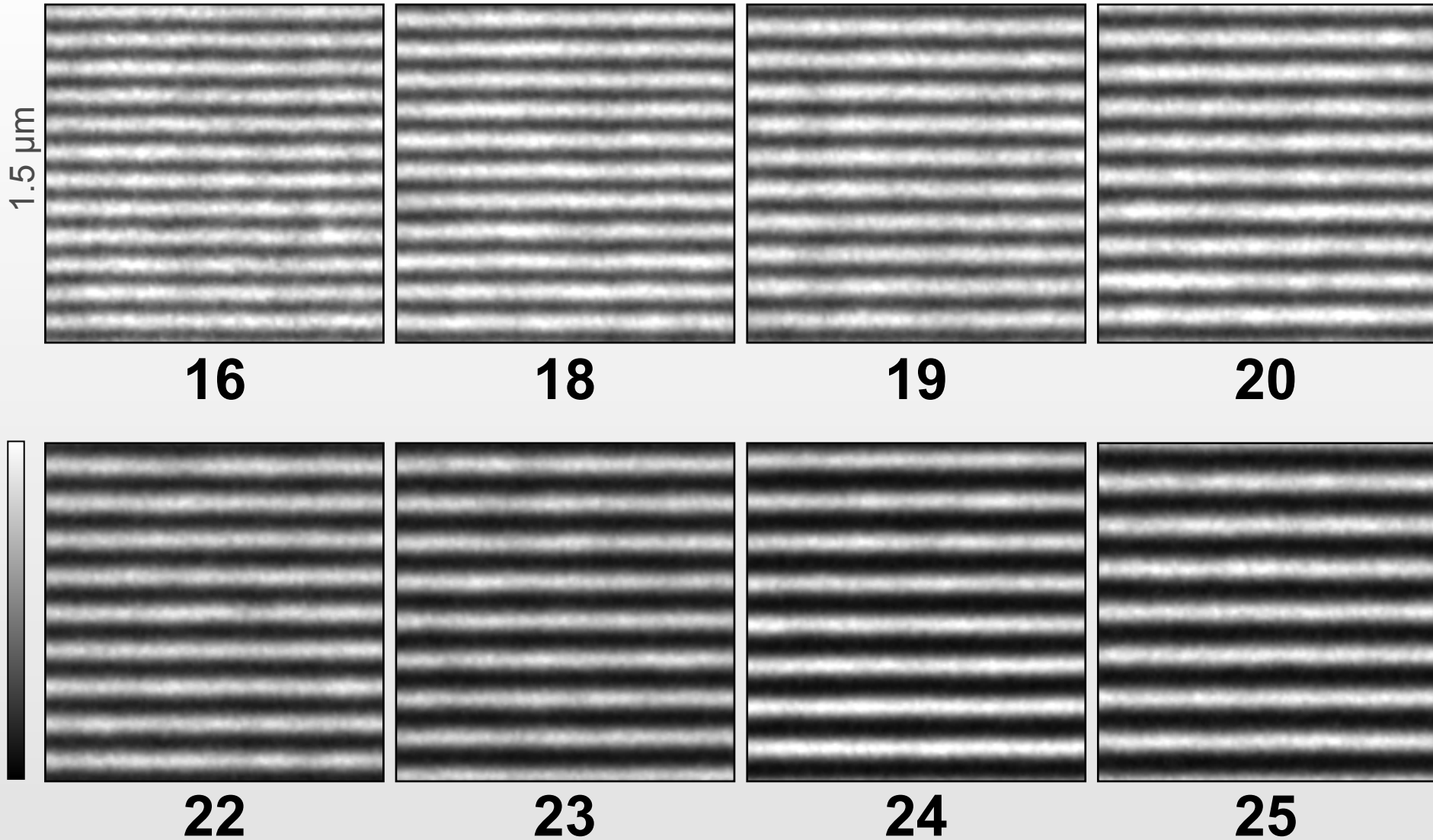


Phase imaging

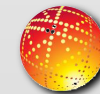


The AIT

The ALT's line contrast reaches down to 16 nm



wafer CD @ 0.35 4×NA



GLOBALFOUNDRIES

Wallow, Mochi, Goldberg: Mask **MET10**

AIT: Calculated performance

8 nm

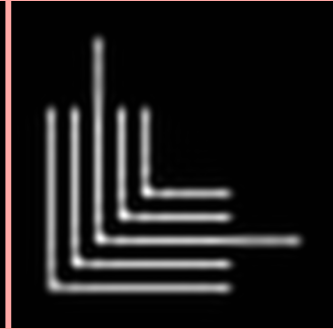
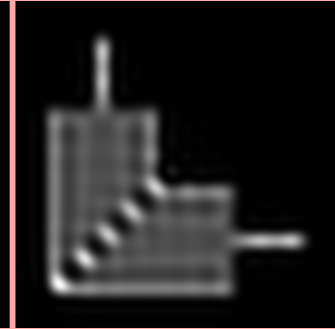
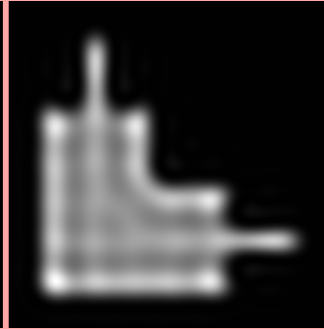
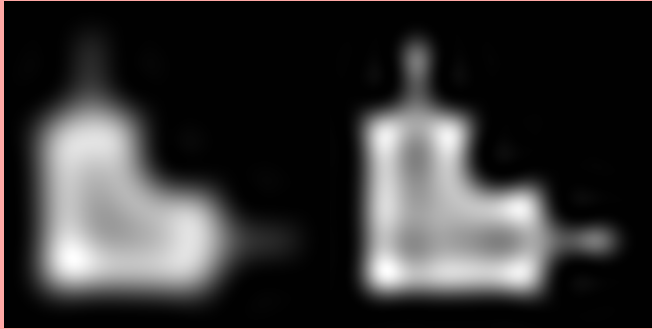
11 nm

16 nm

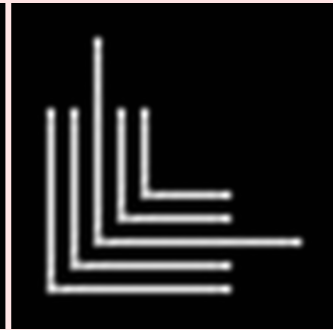
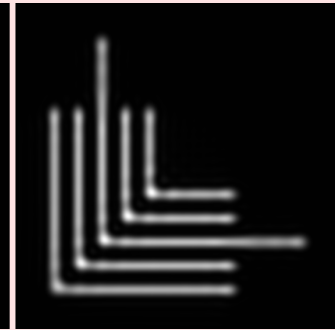
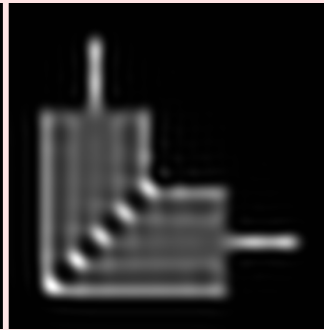
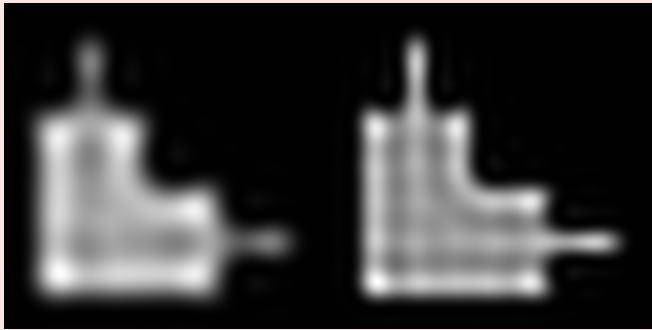
22 nm

32 nm

0.25 NA
 $\sim 0.2 \sigma$

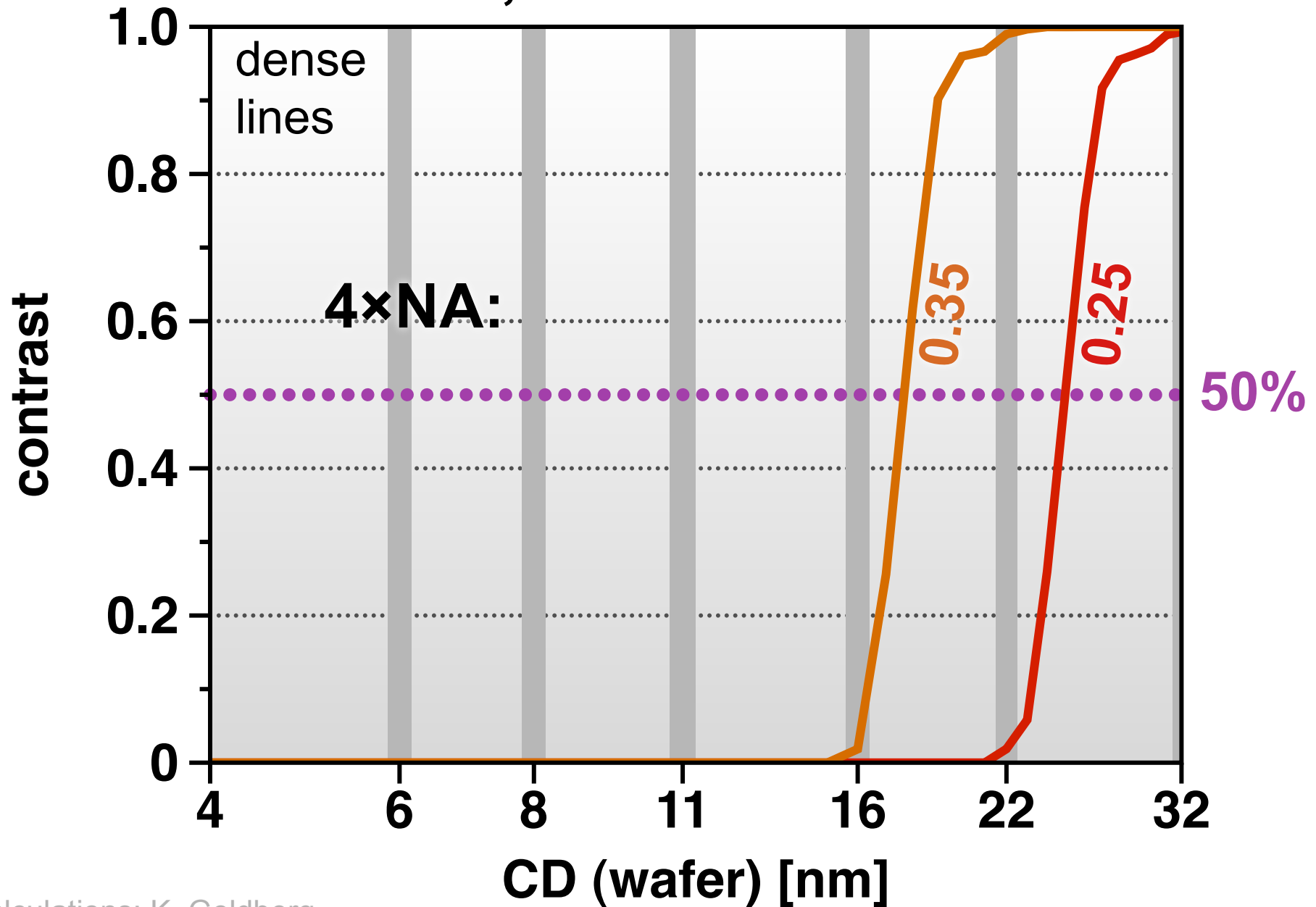


0.35 NA
 $\sim 0.2 \sigma$



AIT Limit

At $\sigma \approx 0.2$, ALT sees ≥ 16 nm



The ALT is 7 years old.



That's 65 in *litho* years.

AIT: Calculated performance

8 nm

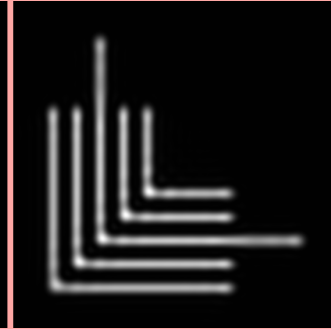
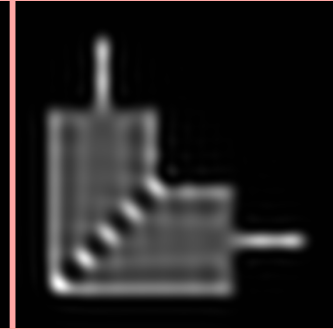
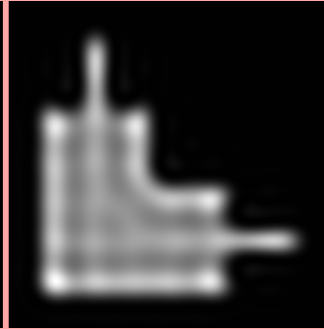
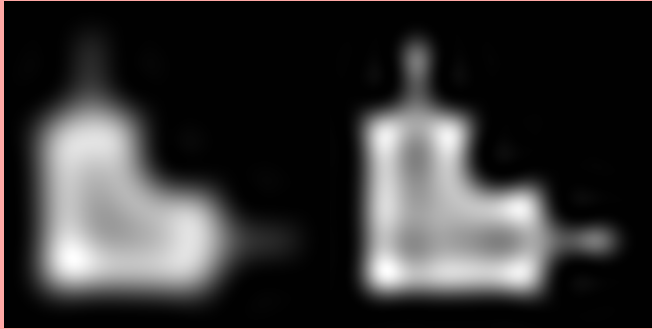
11 nm

16 nm

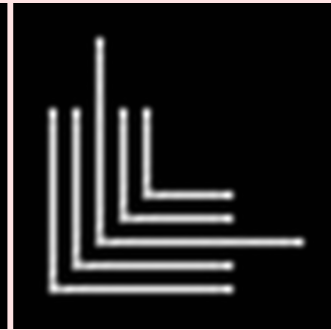
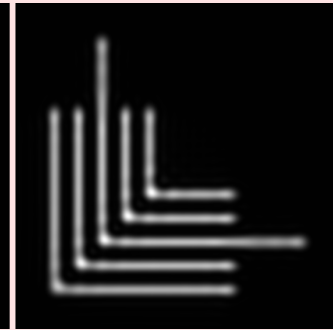
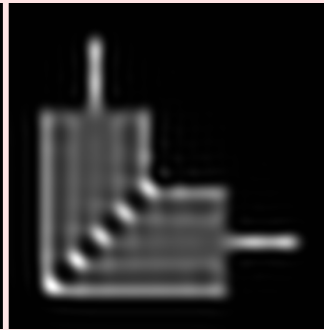
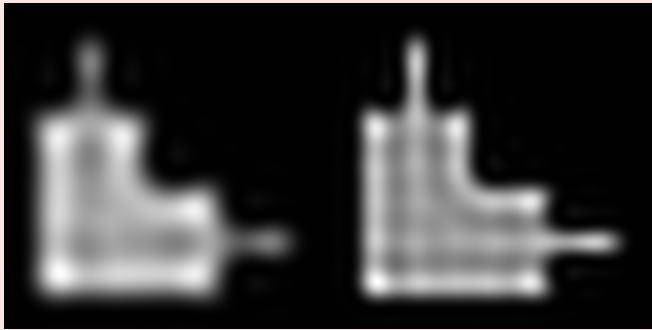
22 nm

32 nm

0.25 NA
 $\sim 0.2 \sigma$



0.35 NA
 $\sim 0.2 \sigma$



AIT Limit

Higher resolution needs high NA and σ control

8 nm

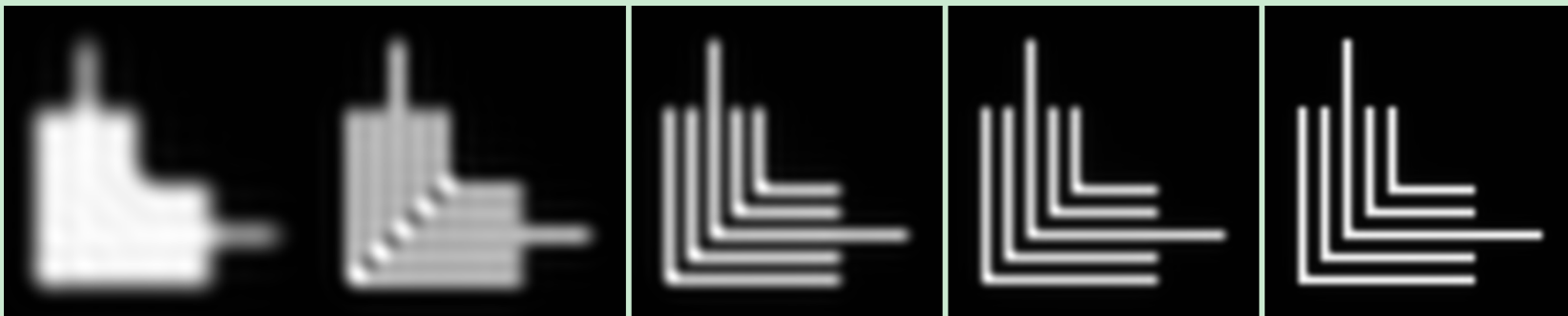
11 nm

16 nm

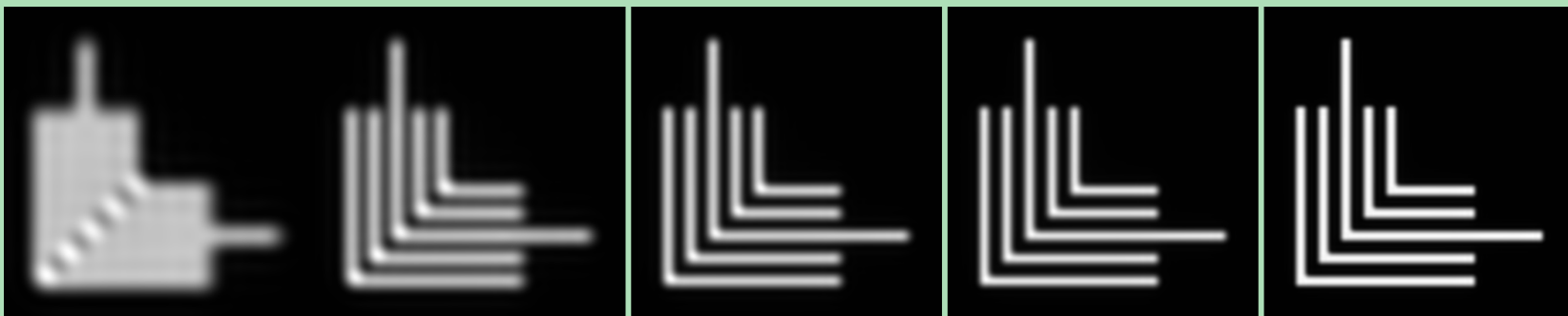
22 nm

32 nm

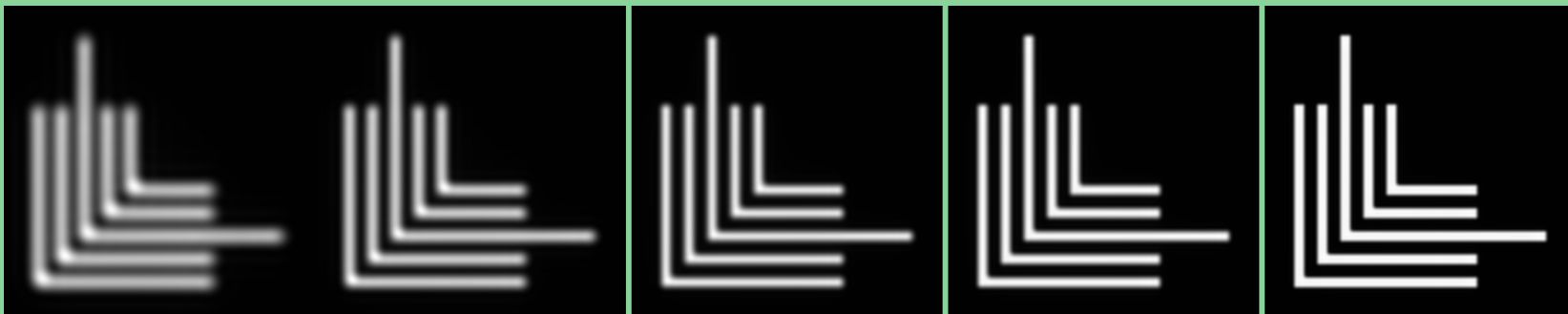
0.35 NA
0.8 σ



0.45 NA
0.8 σ

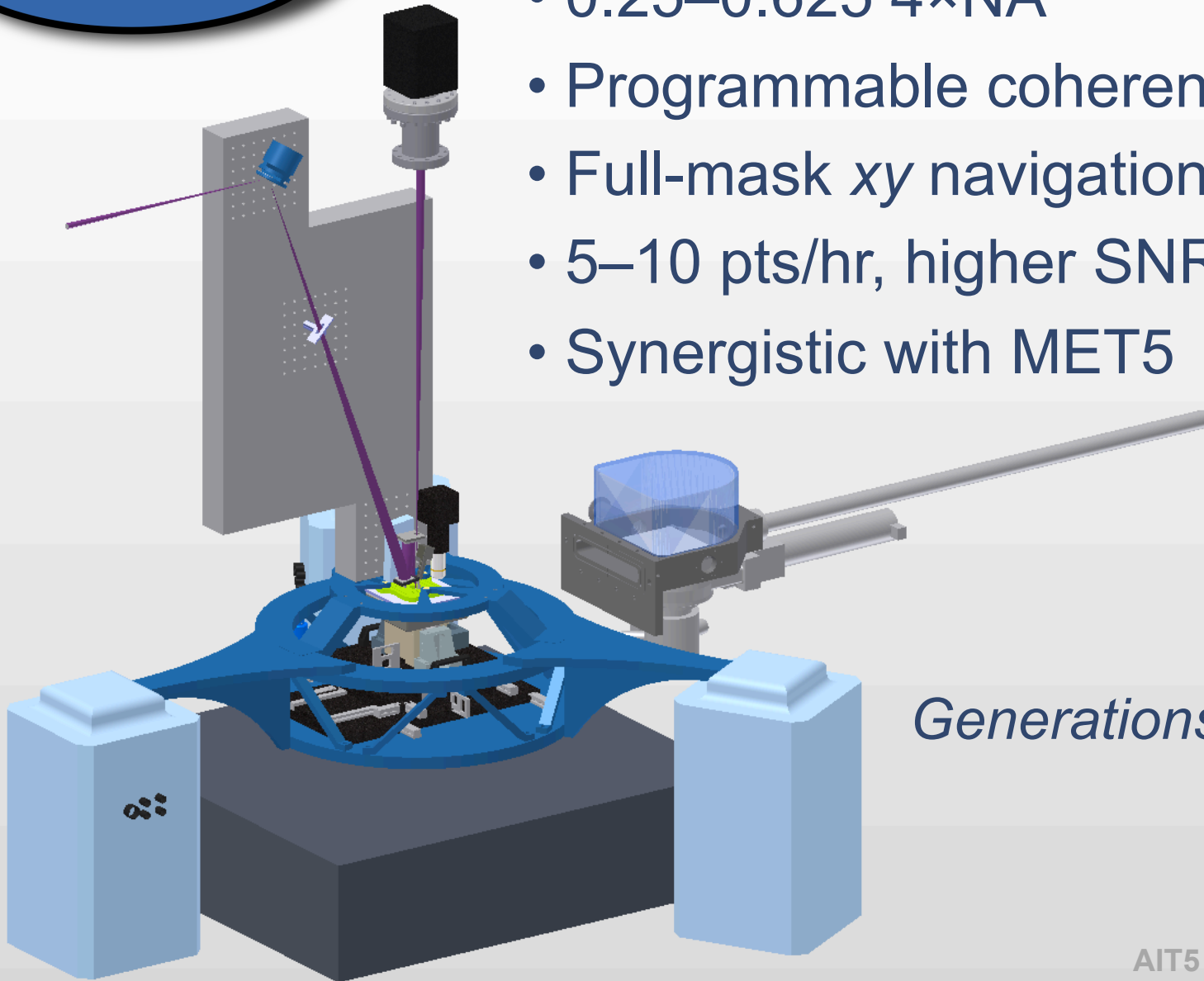


0.62 NA
0.8 σ





- Zoneplate-lens imaging
- 0.25–0.625 4×NA
- Programmable coherence, σ
- Full-mask xy navigation
- 5–10 pts/hr, higher SNR
- Synergistic with MET5



Generations Ahead

AIT5: High-Quality, Efficient, 18 Months

Optics and Illumination

Zoneplate lens array

- Variable NA
- Diffraction-limited performance
- Low flare

Coherence and uniformity

Mag: 250–4000x

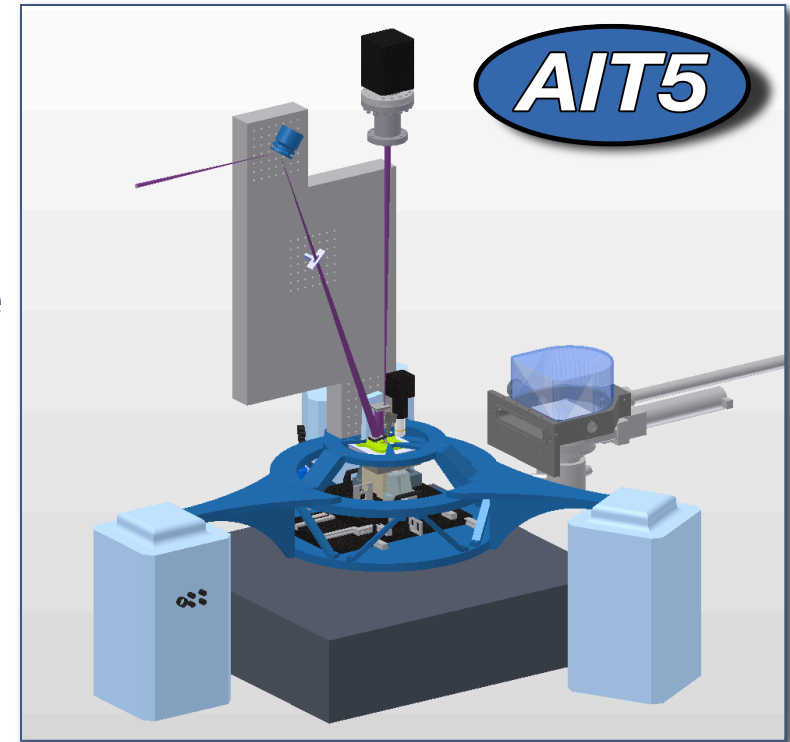
Navigation

Integrated visible-light microscope
& Low-mag EUV zoneplate

Synchrotron Source

Clean, reliable

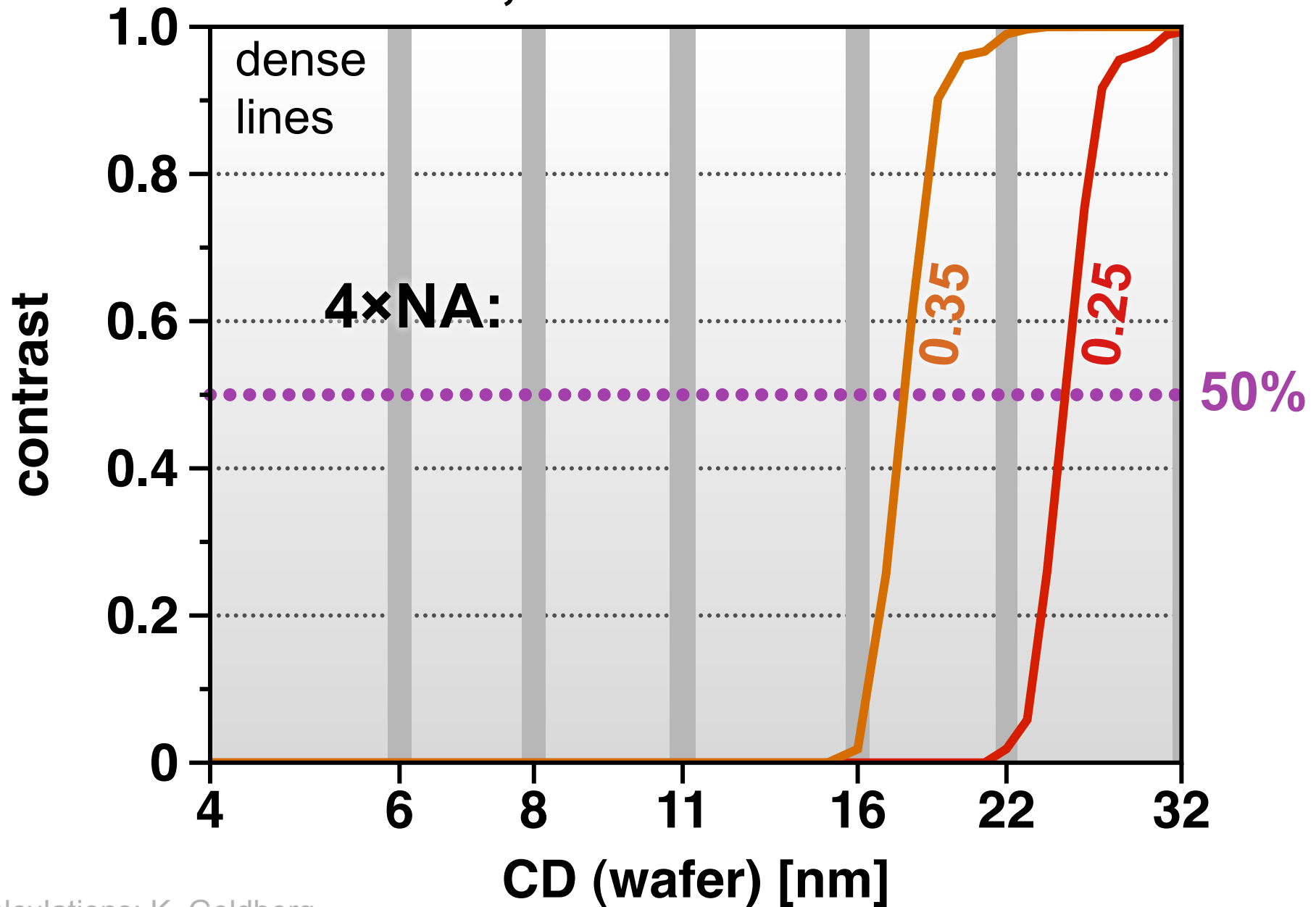
Stable Imaging



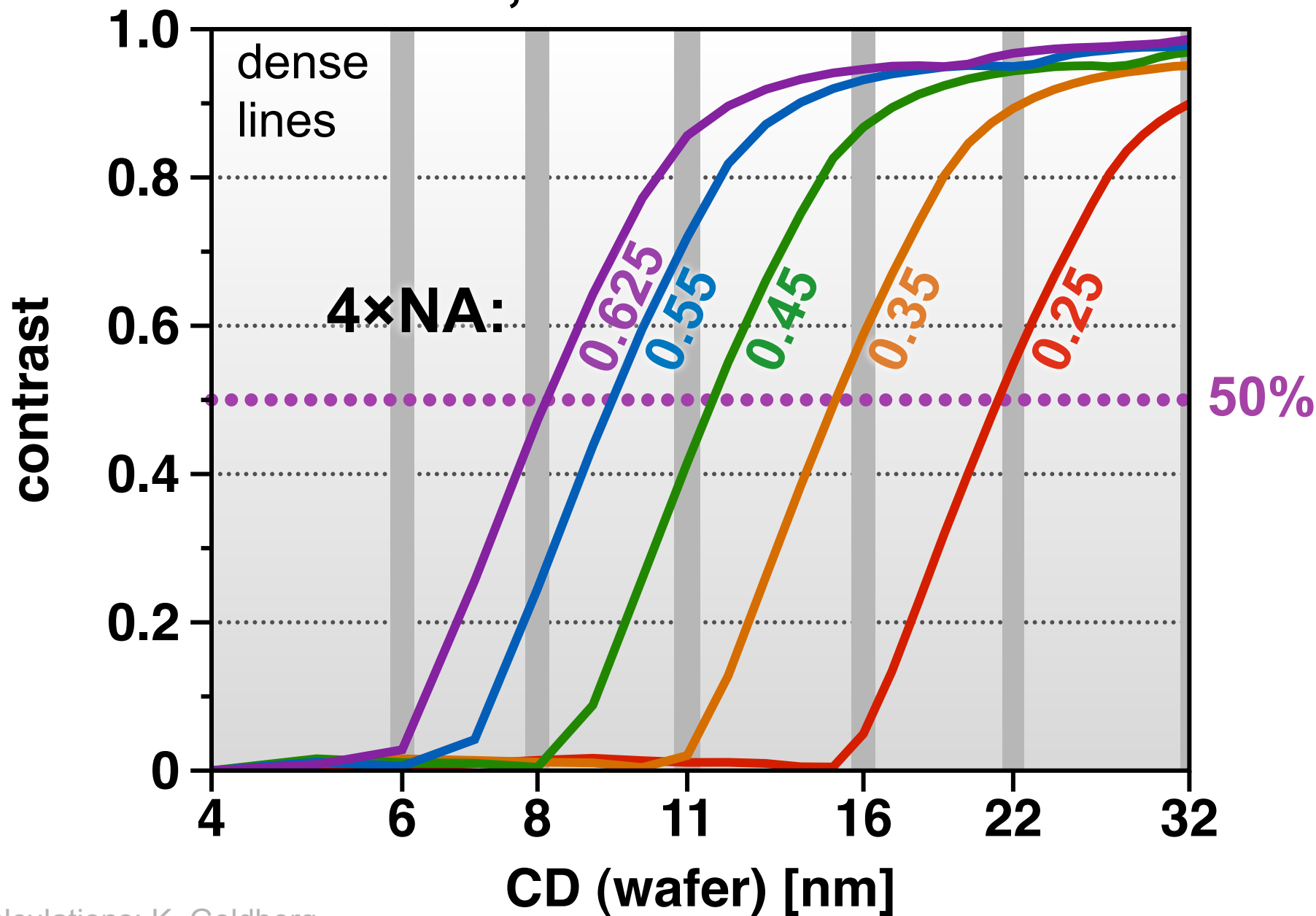
LBL R&D Team

Built by the same team
that runs *AIT* and *MET*
for SEMATECH.

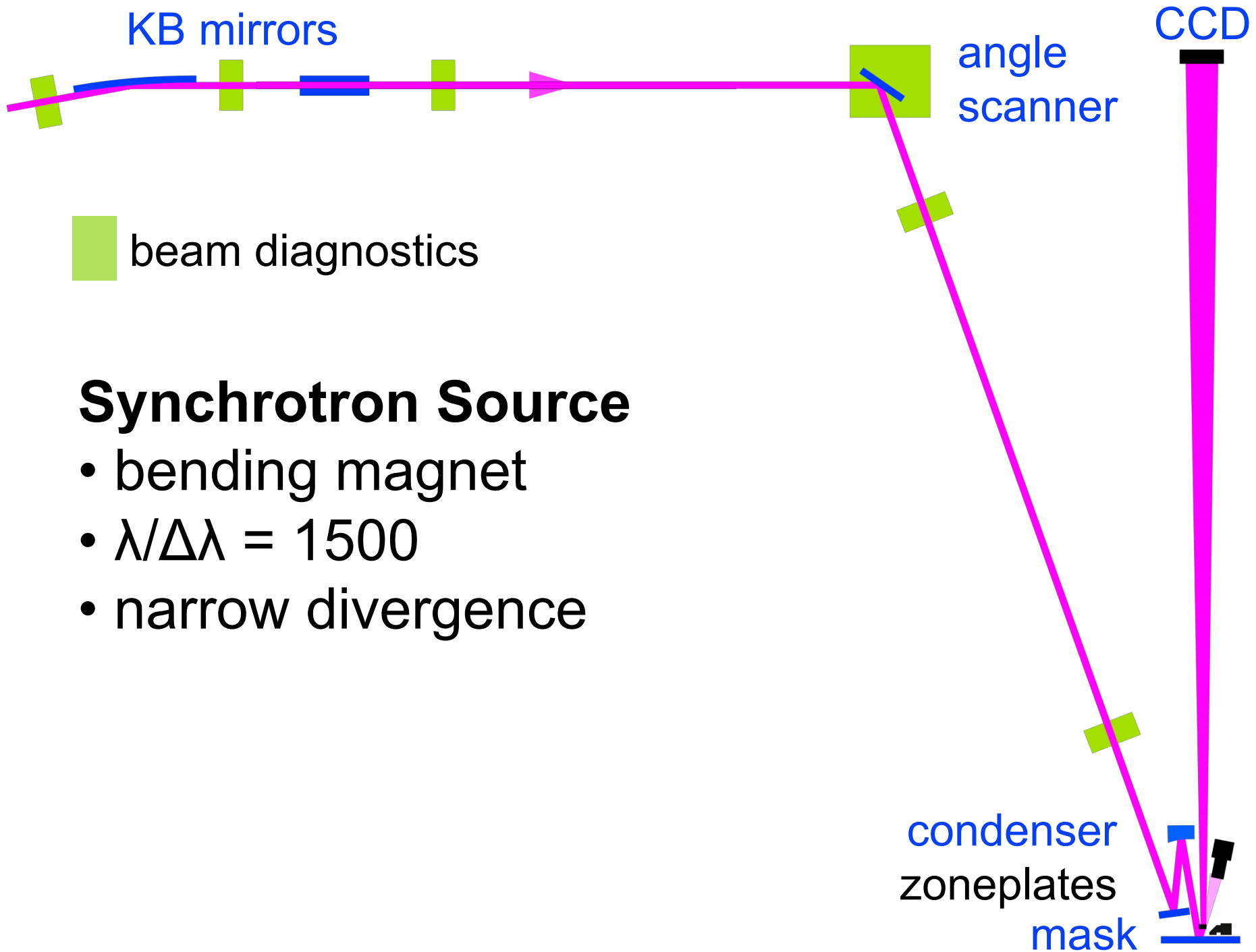
At $\sigma \approx 0.2$, ALT sees ≥ 16 nm



At $\sigma = 0.8$, ALT5 will see > 6 nm



KB mirrors



angle
scanner

CCD

beam diagnostics

Synchrotron Source

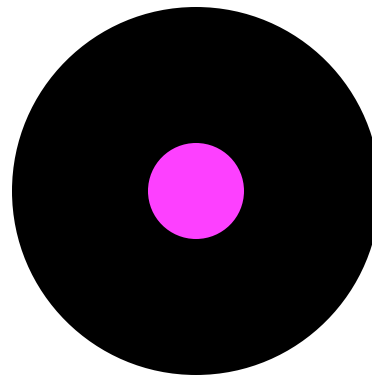
- bending magnet
- $\lambda/\Delta\lambda = 1500$
- narrow divergence

condenser
zoneplates
mask

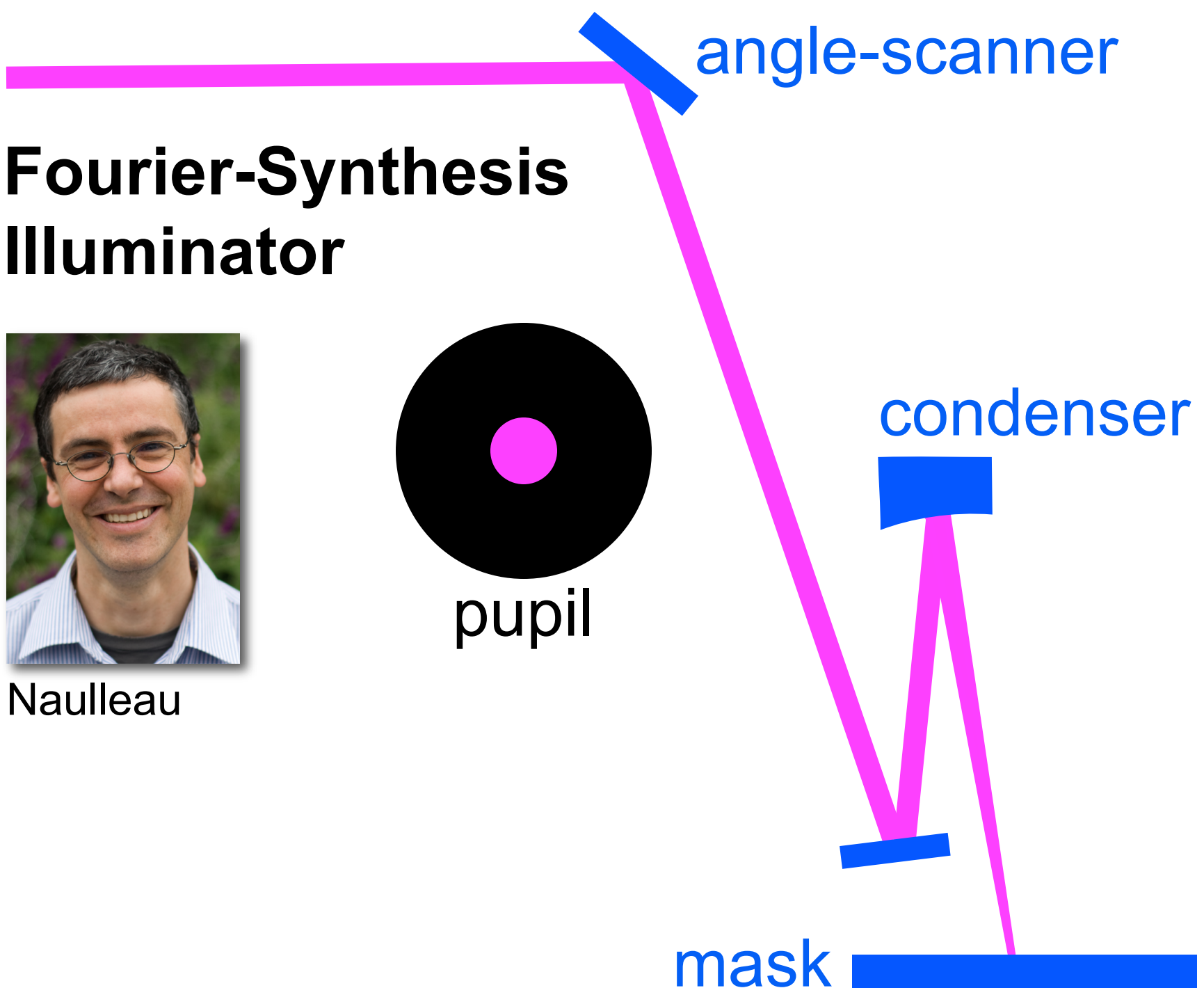
Fourier-Synthesis Illuminator



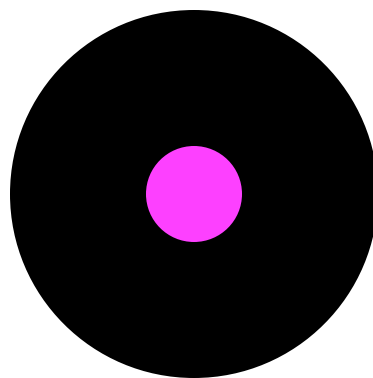
Naulleau



pupil



Fourier-Synthesis Illuminator



pupil



angle-scanner

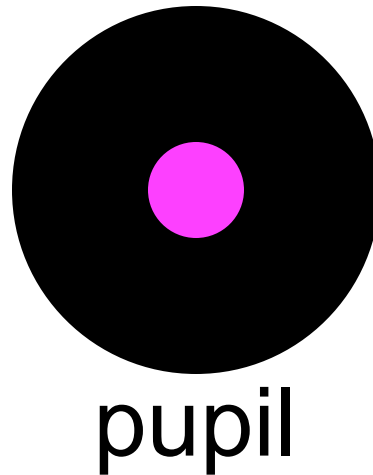
condenser



mask



Fourier-Synthesis Illuminator



angle-scanner

- diamond-turned
- HSQ smoothed
- ML coated

condenser

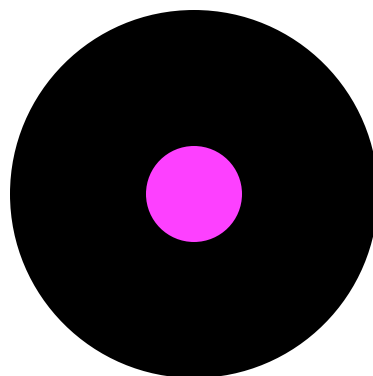
pupil

Soufli, *Opt. Eng.* **43** (12), 2004.
Salmassi, *Appl. Opt.* **45** (11), 2006.

mask

~15 μm

Fourier-Synthesis Illuminator

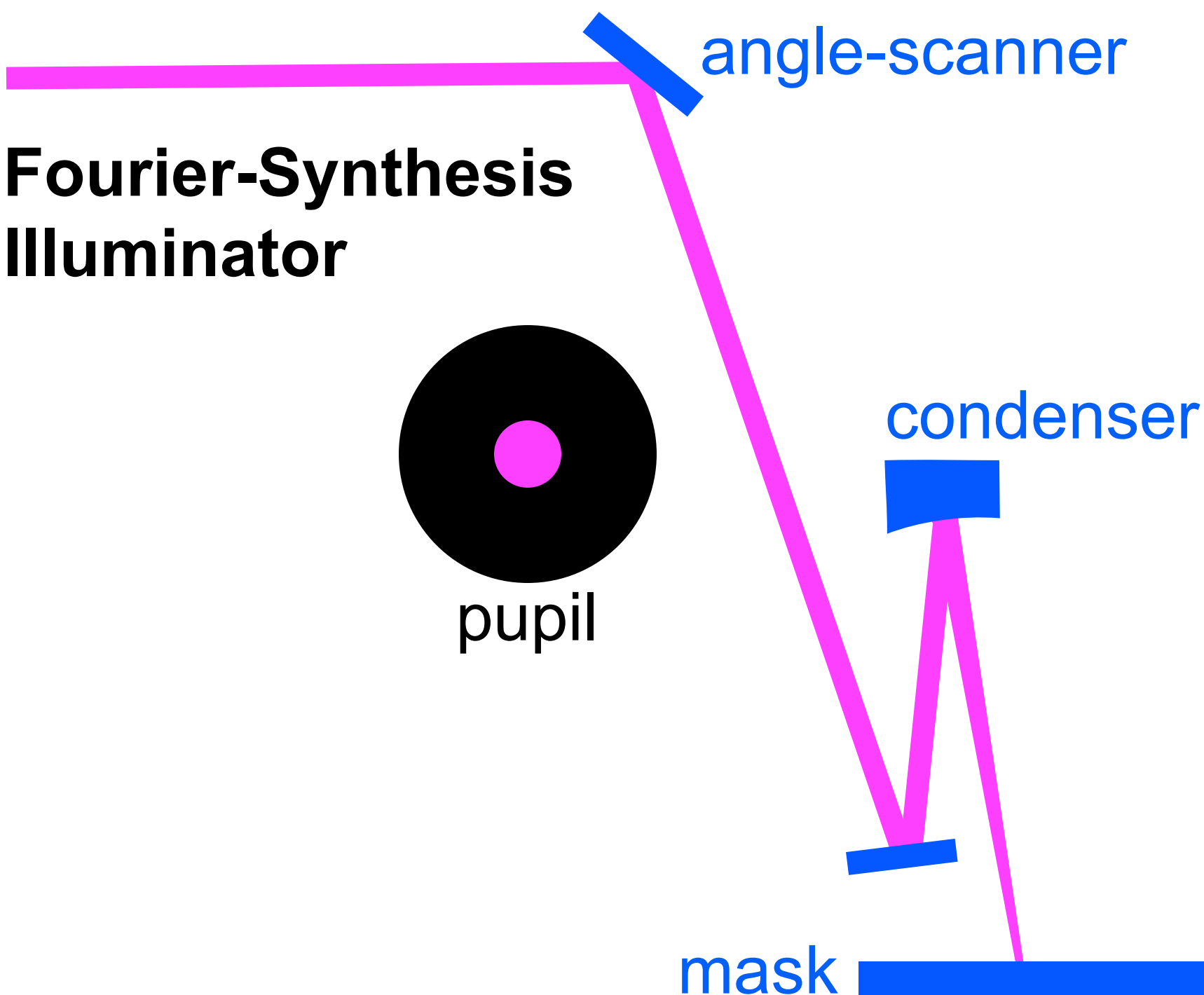


pupil

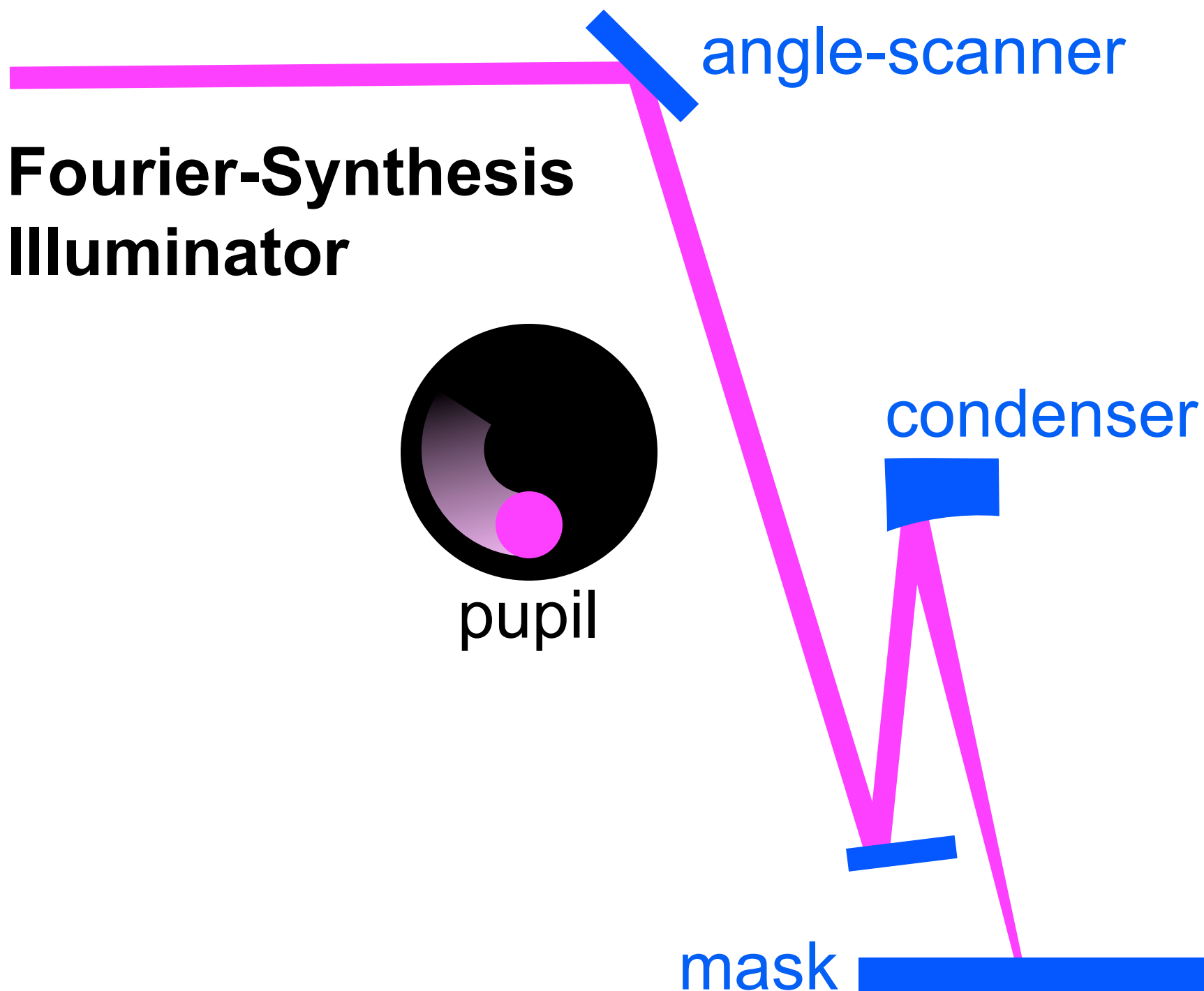
angle-scanner

condenser

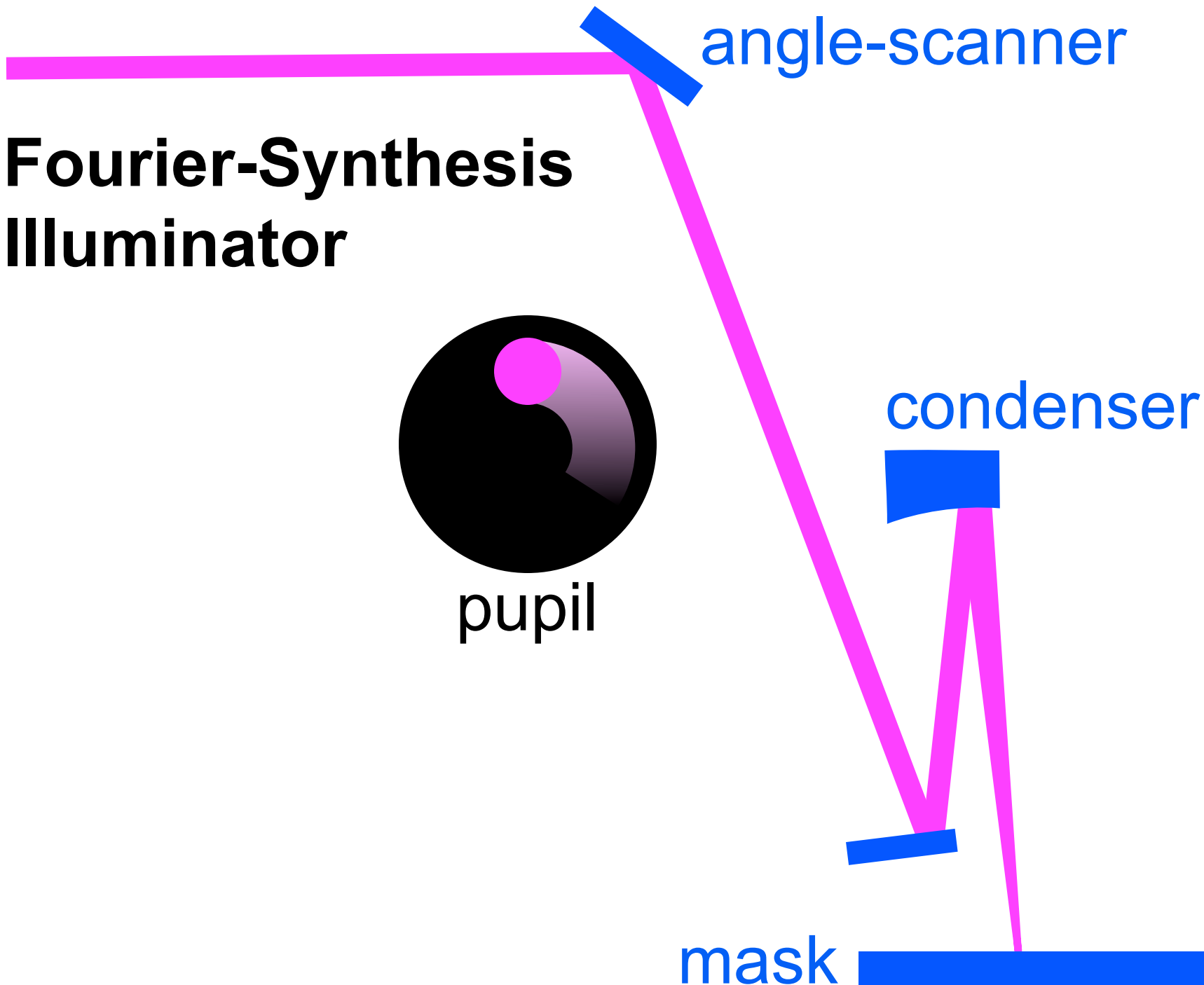
mask



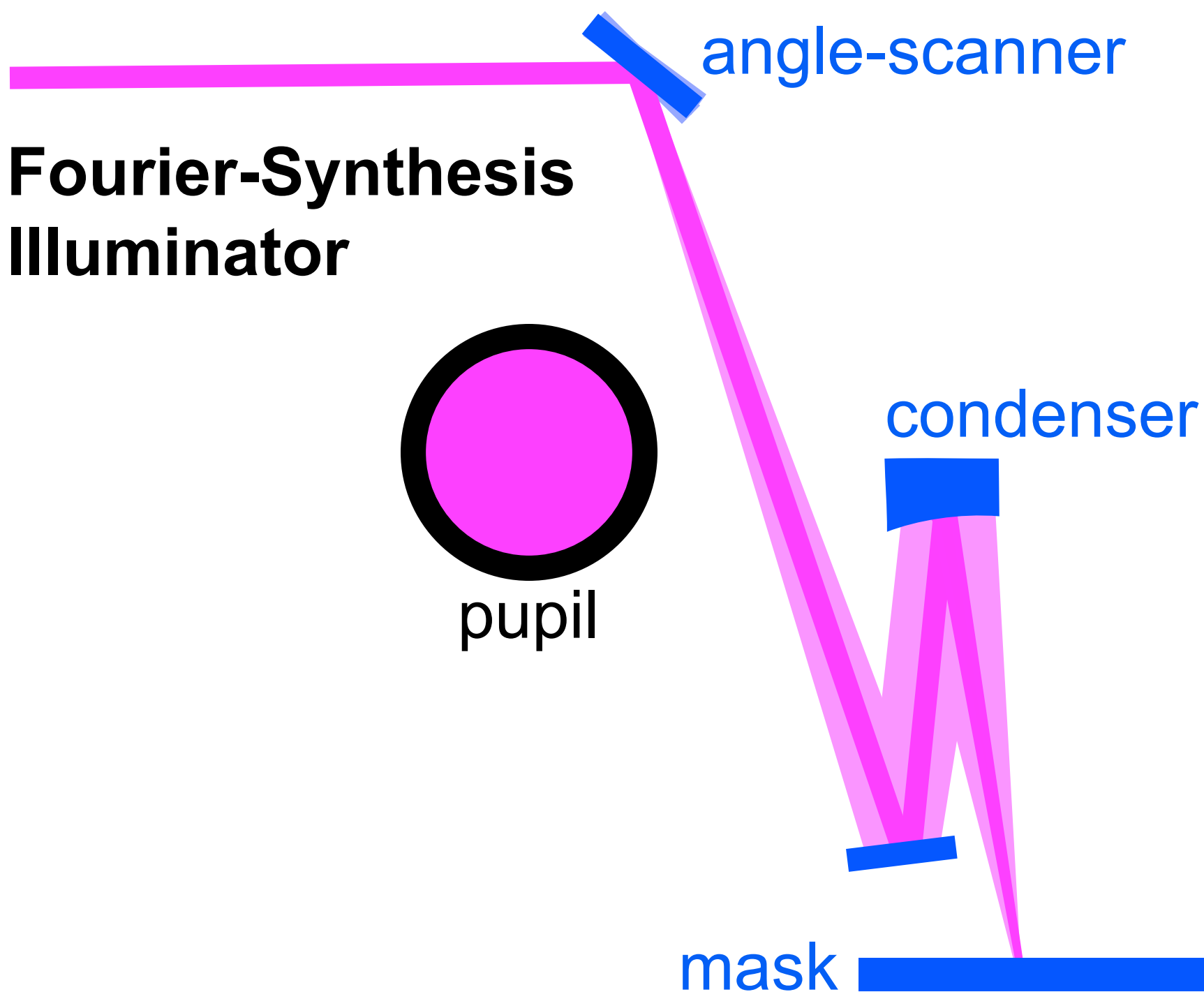
Fourier-Synthesis Illuminator



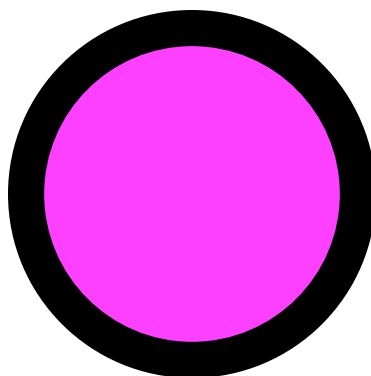
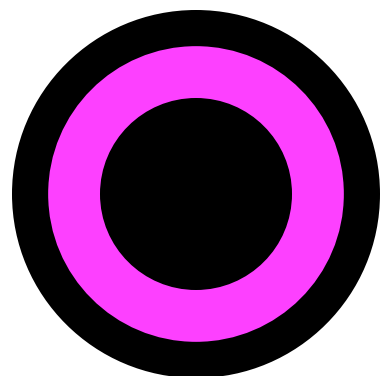
Fourier-Synthesis Illuminator



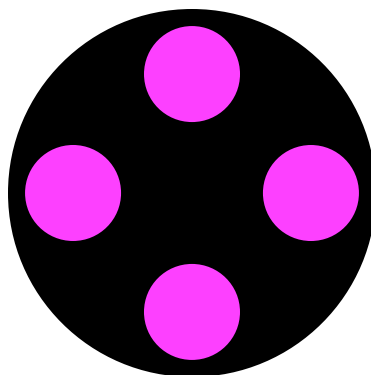
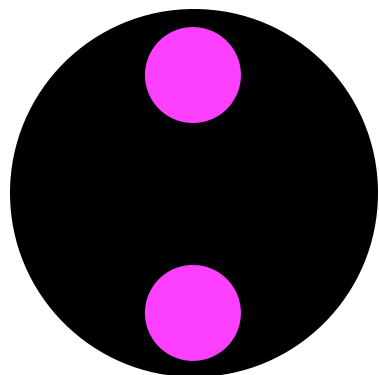
Fourier-Synthesis Illuminator



Fourier-Synthesis Illuminator



pupil



angle-scanner

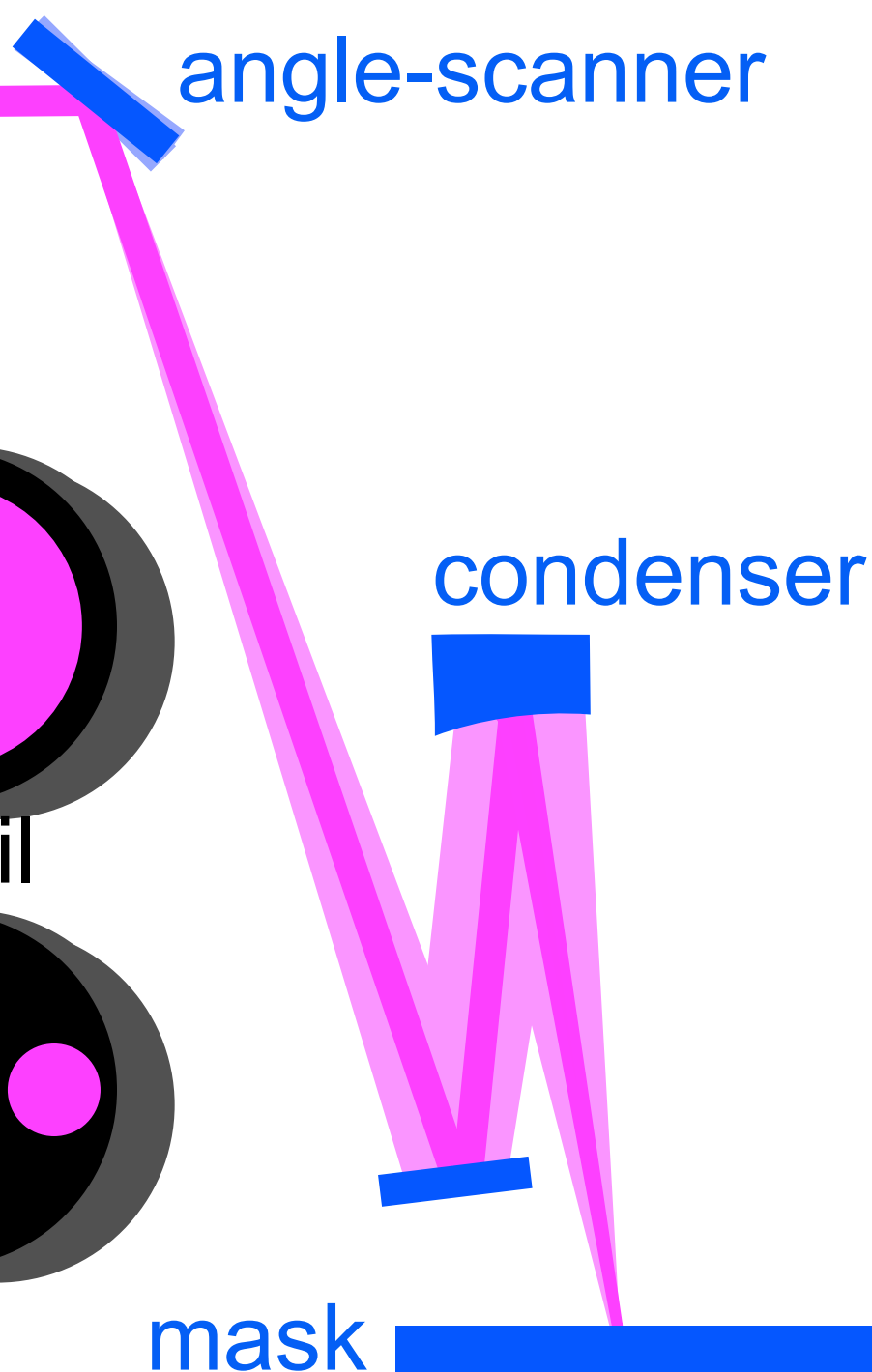
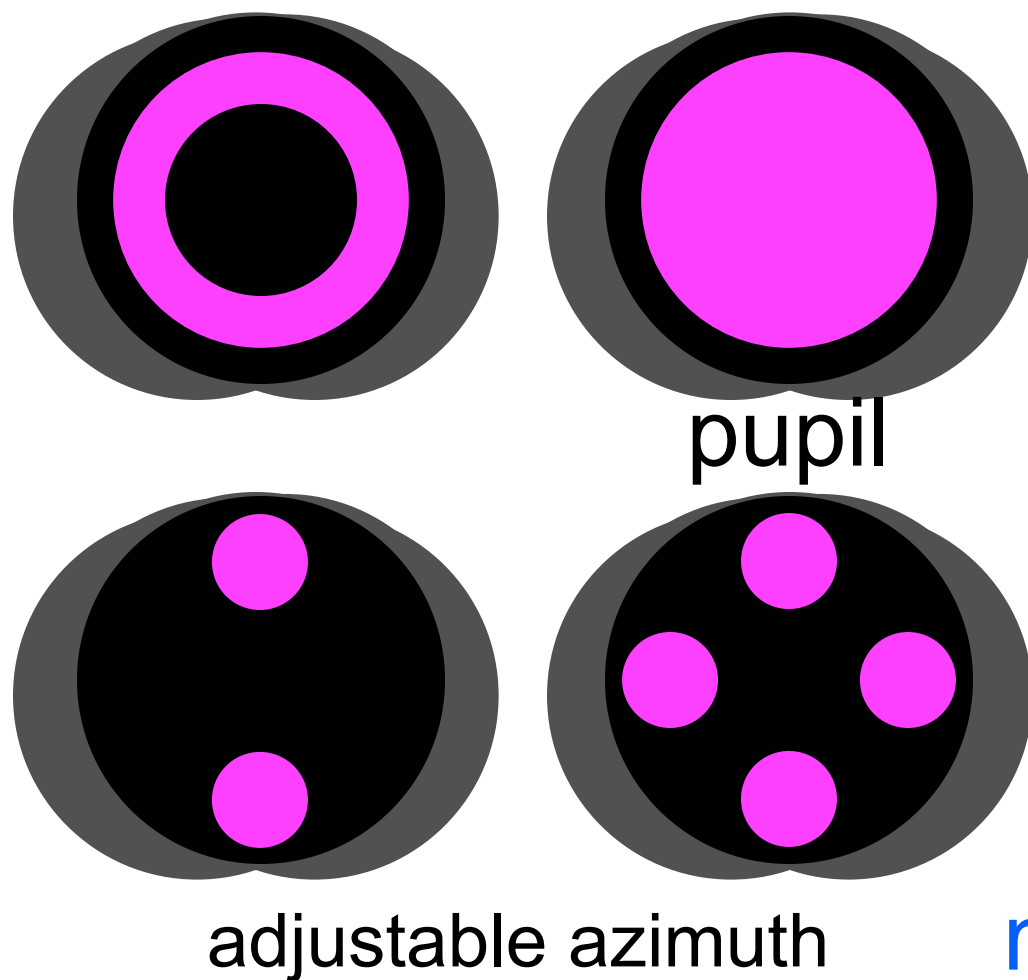
condenser



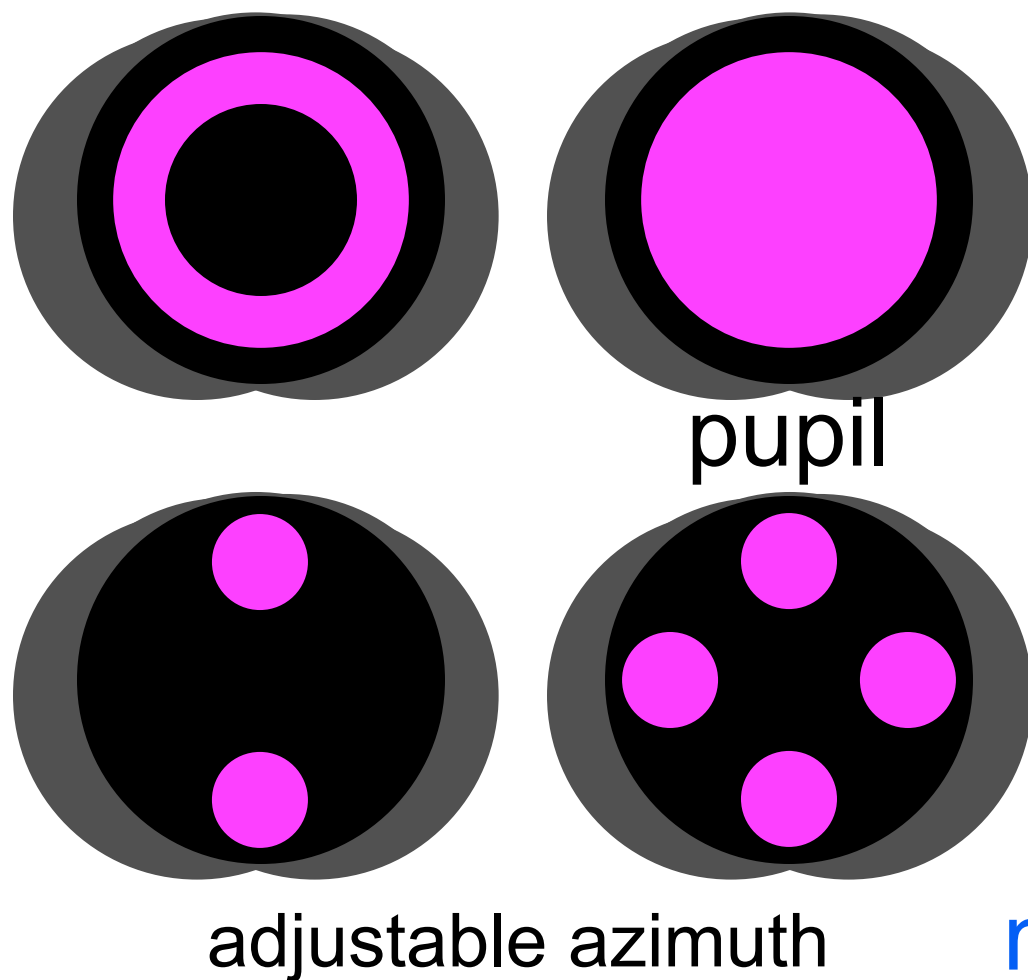
mask



Fourier-Synthesis Illuminator



Fourier-Synthesis Illuminator

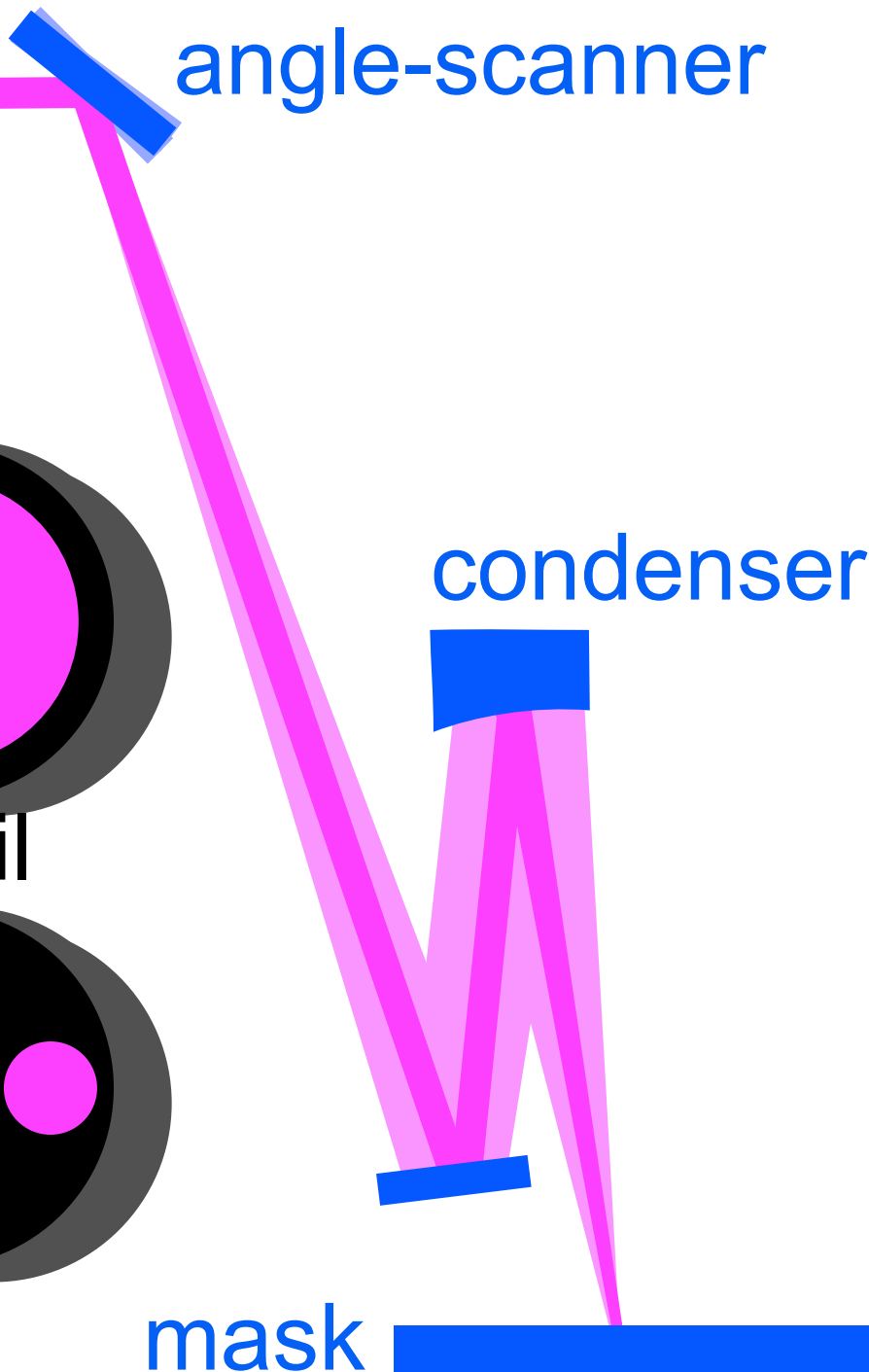


pupil

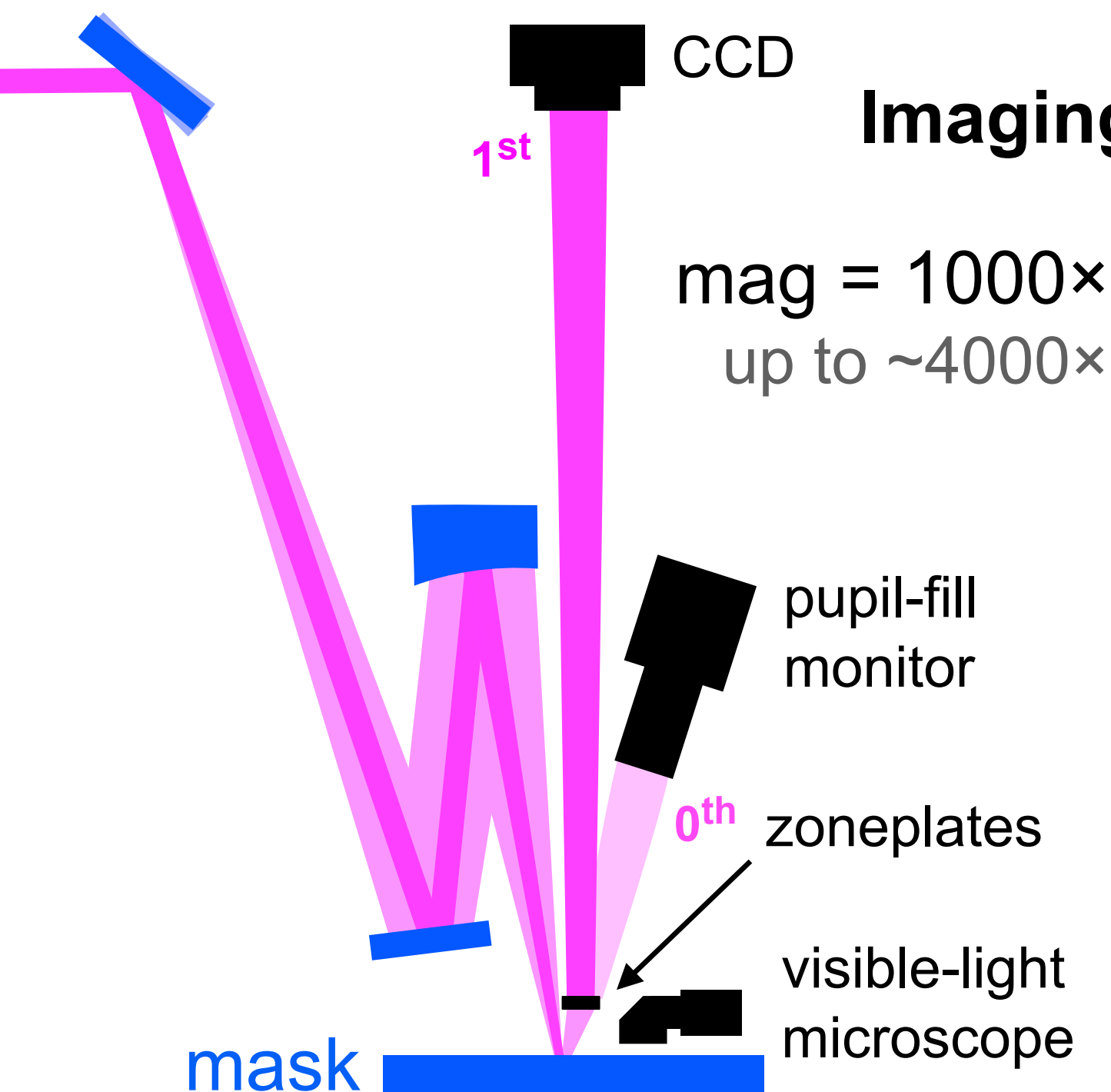
angle-scanner

condenser

mask

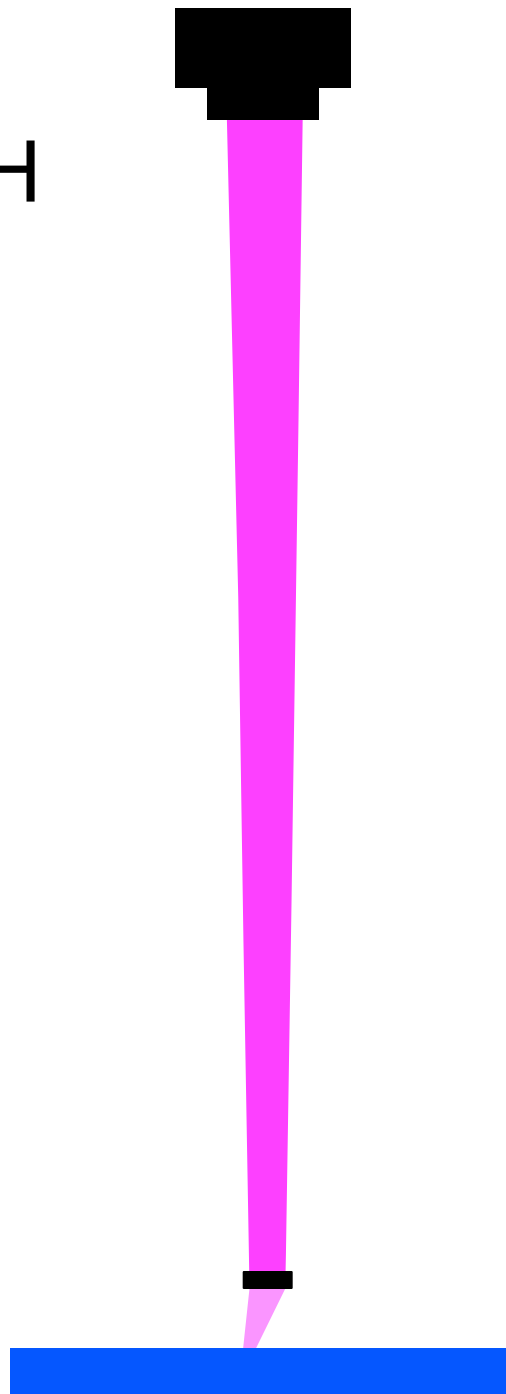


Imaging System



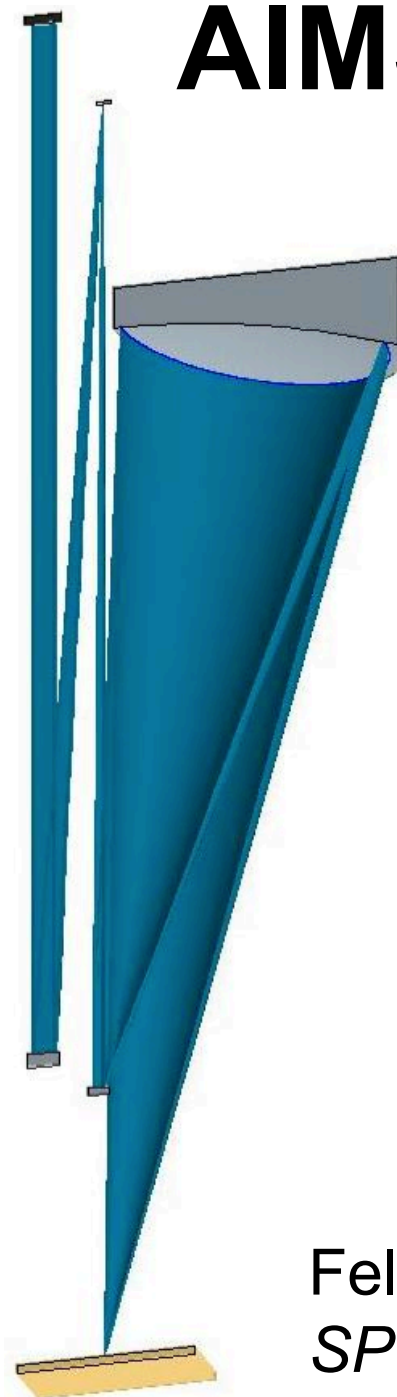
AIT5

SEMATECH
& LBNL



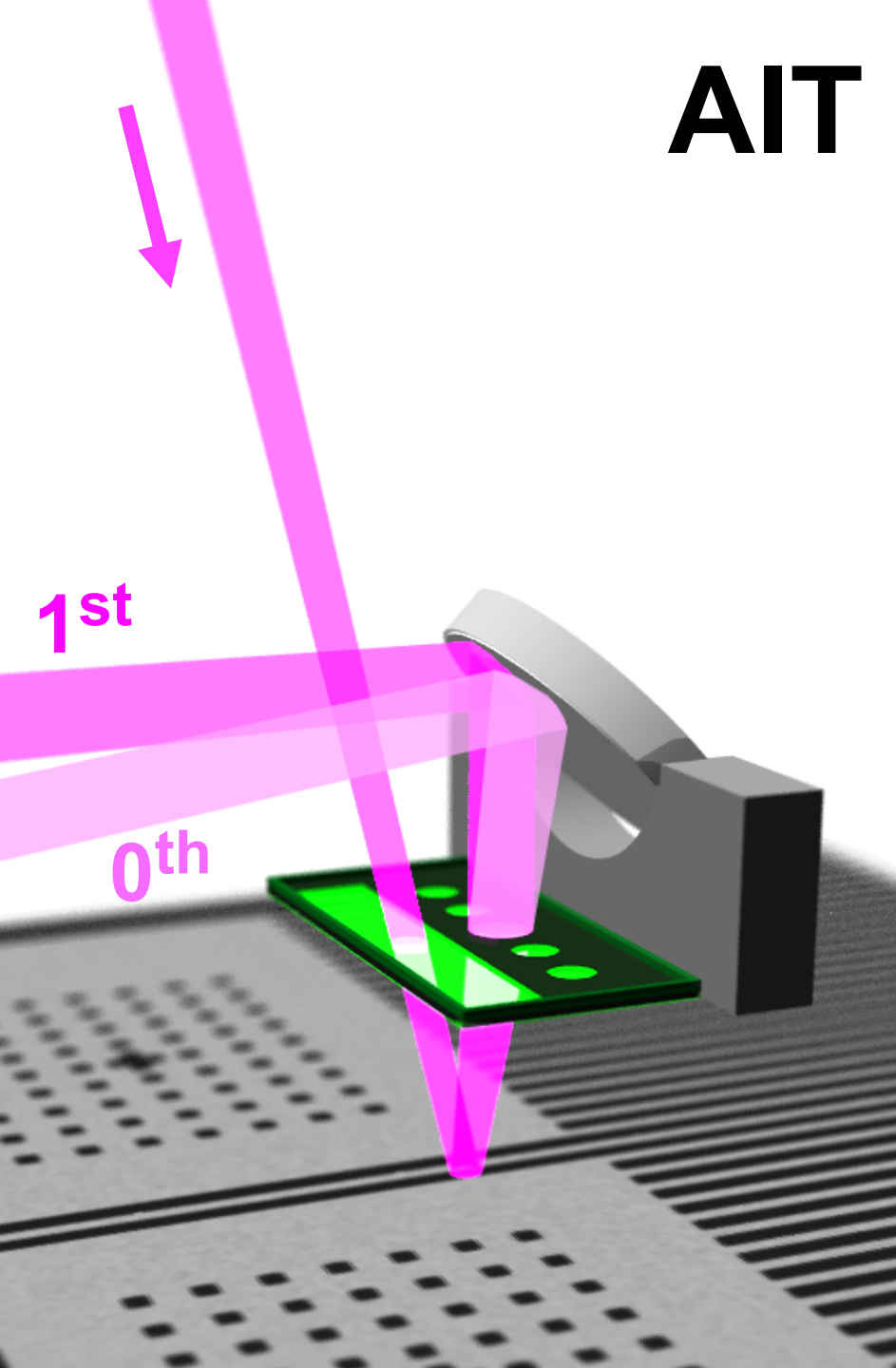
AIMS™ EUV

Zeiss

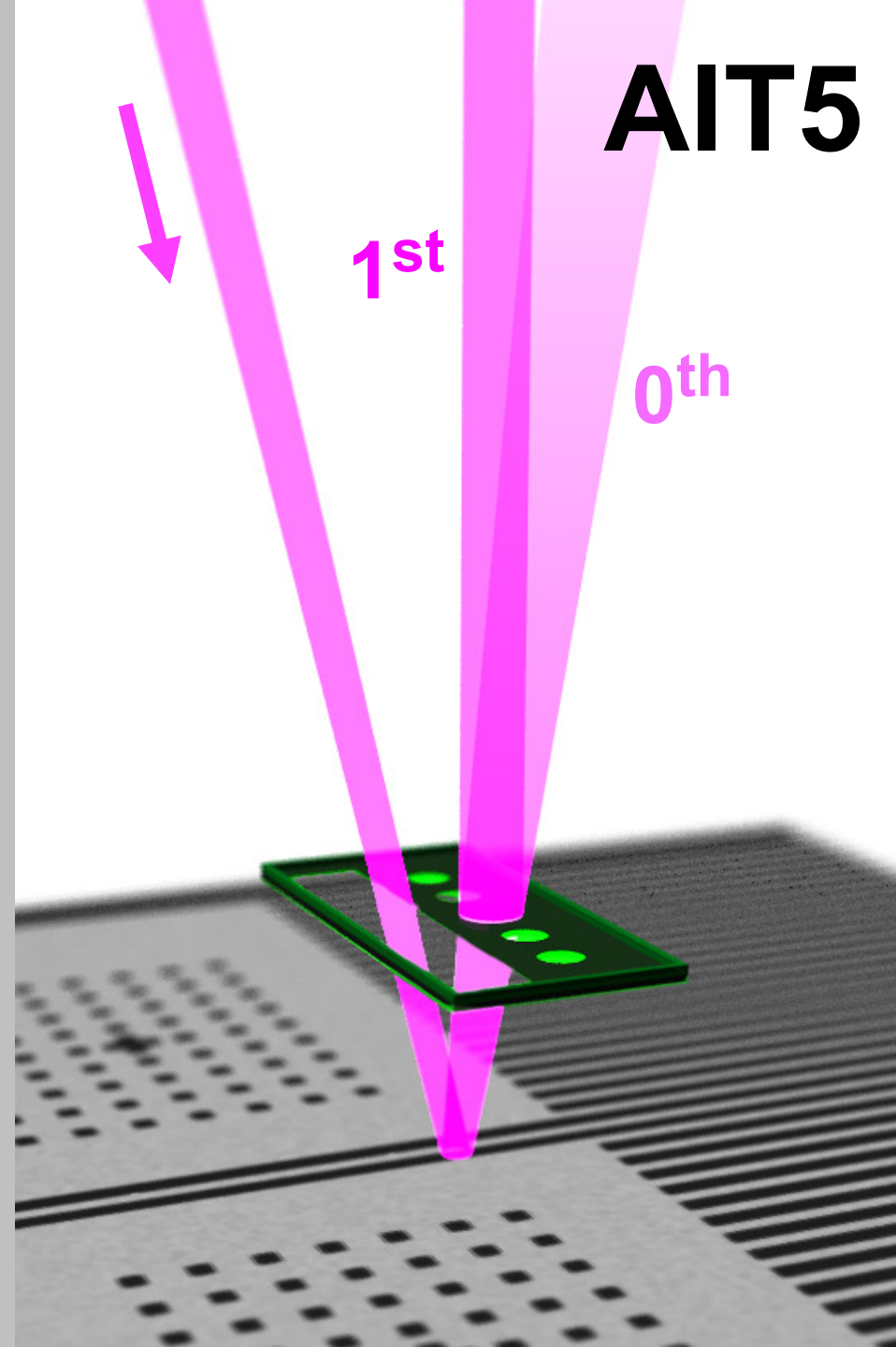


Feldmann,
SPIE 7636 (2010)

AIT



AIT5



Zoneplate objective lenses arrayed by NA

6°

8°

10°

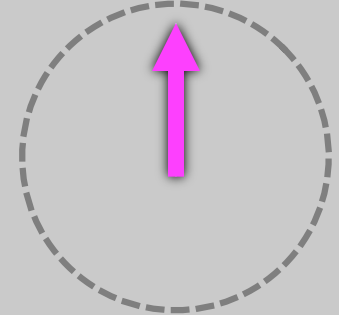
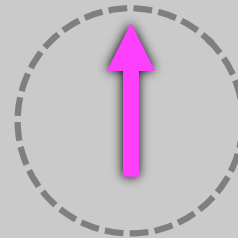
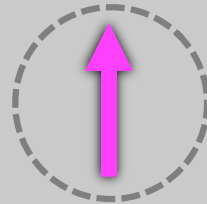
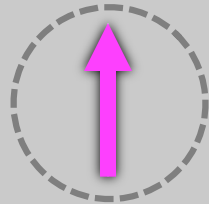
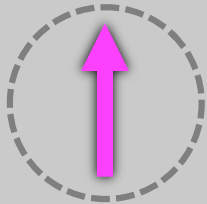
4xNA: 0.25

0.30

0.35

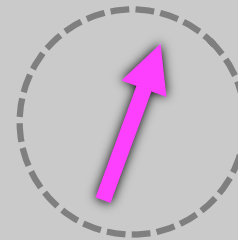
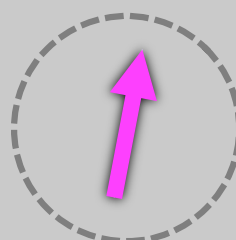
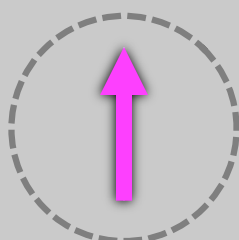
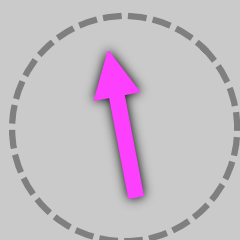
0.45

0.625

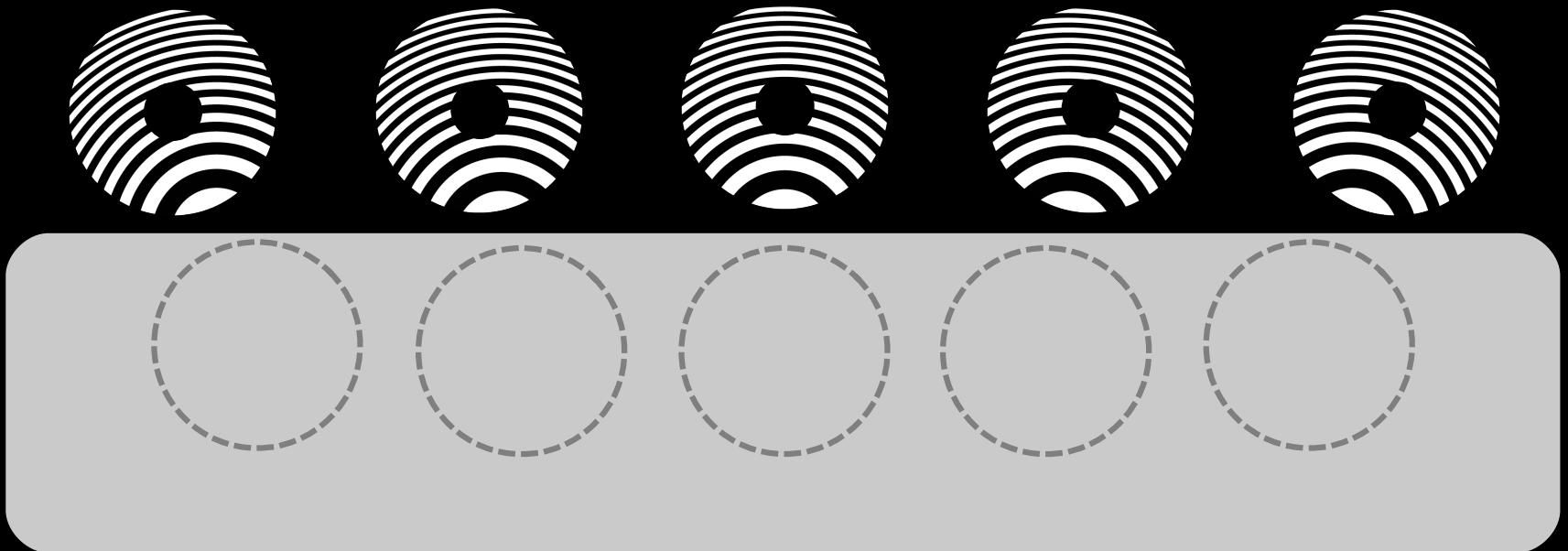


Zoneplate objective lenses arrayed by azimuthal angle

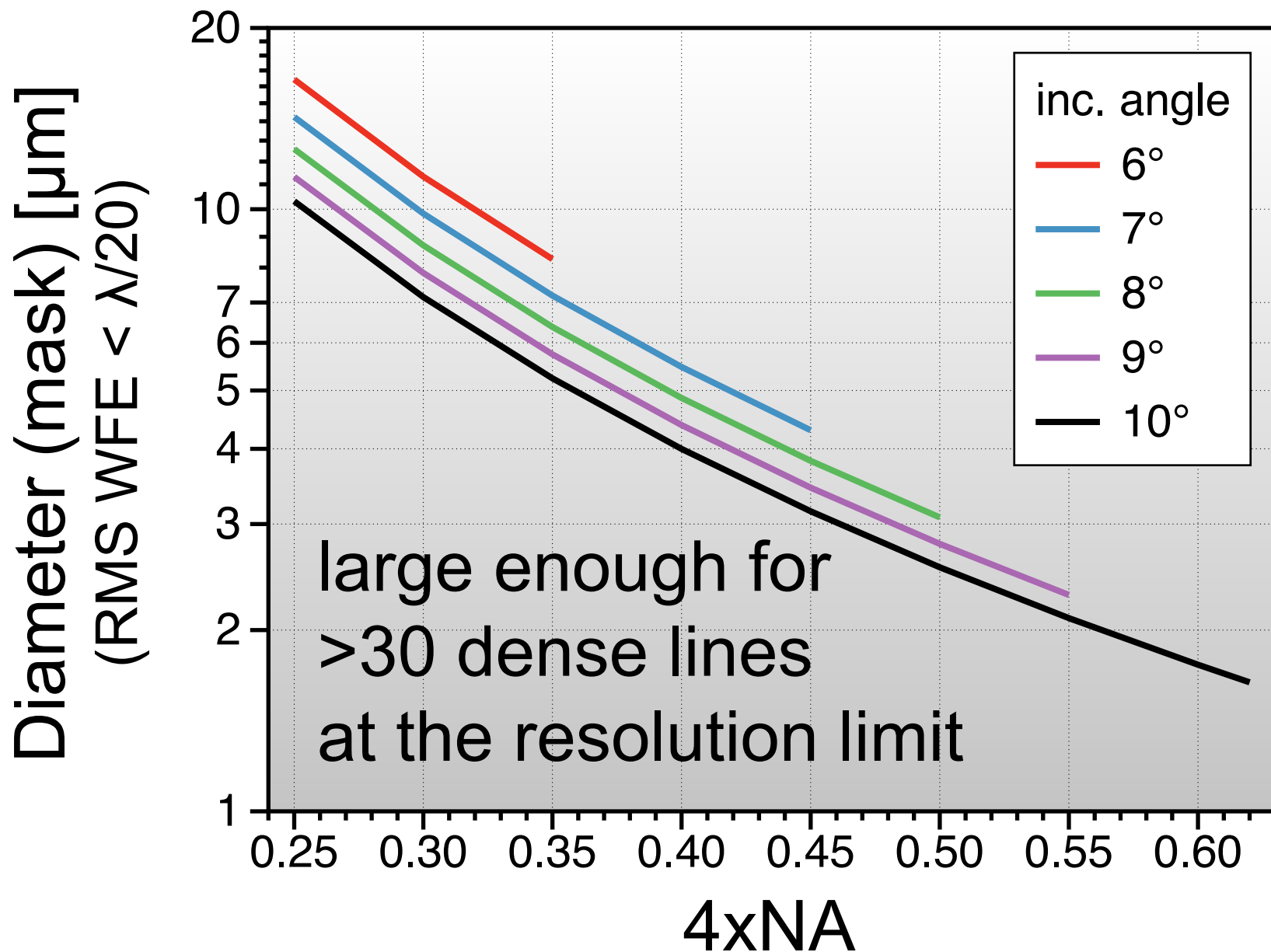
Φ : -25° -12.5° 0° 12.5° 25°



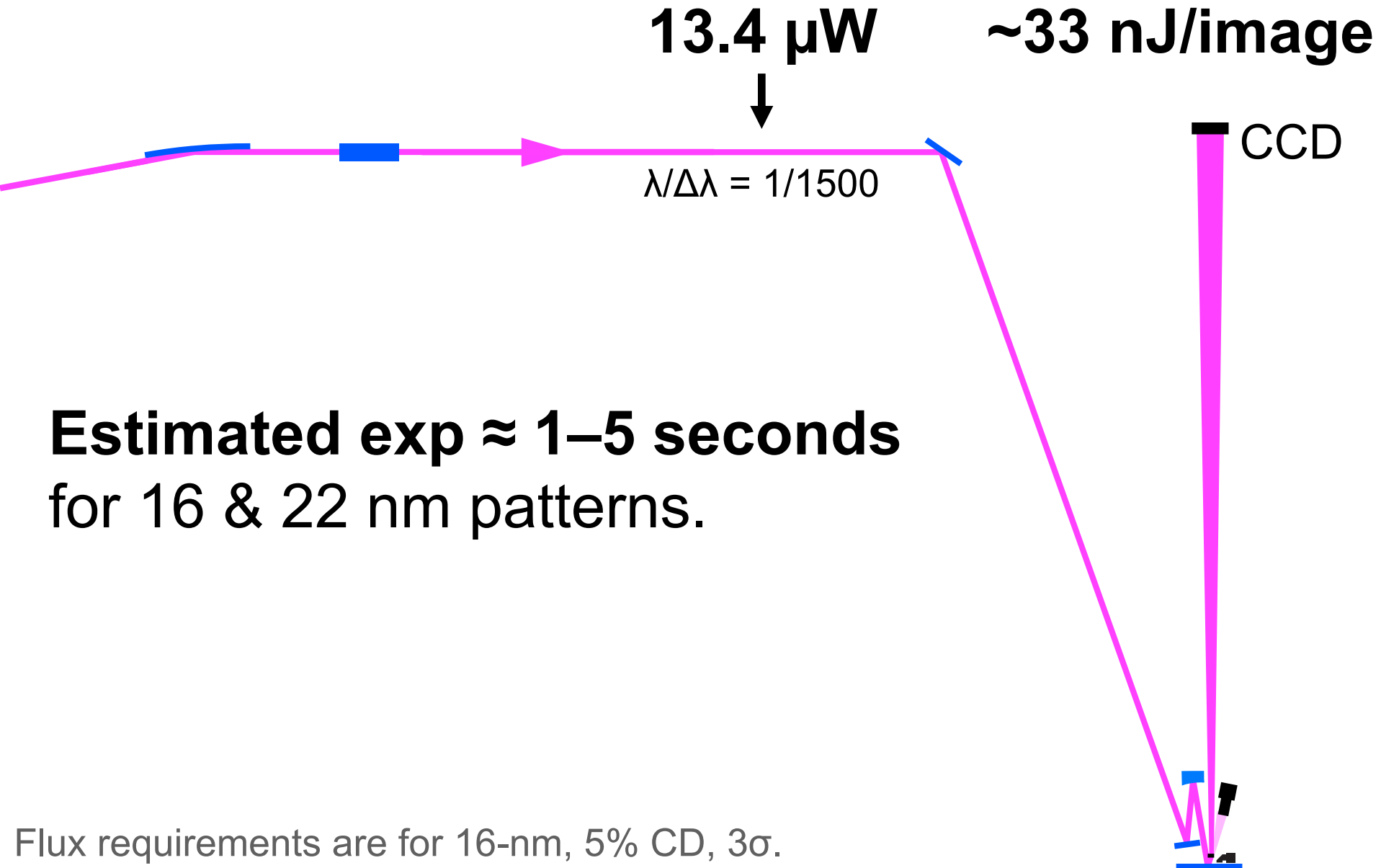
Zoneplate objective lenses arrayed by azimuthal angle



Diffraction-Limited Imaging *Sweet-Spot*



What about *power*?



Estimated exp $\approx 1\text{--}5$ seconds
for 16 & 22 nm patterns.

Flux requirements are for 16-nm, 5% CD, 3σ .
Wintz, *SPIE* **7636** (2010).

AIT

> 16 nm

low σ

$\angle 6^\circ$

AIT5

> 6 nm

any σ

up to $\angle 10^\circ$



Ready in 18 months. . .

The AIT team



Iacopo Mochi
Project Scientist



James Macdougall
Graduate Student



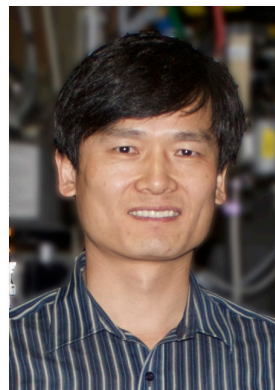
Nathan Smith
Engineering Associate



Seno Rekawa
Chief Engineer



Ken Goldberg
Principal Investigator



Harry Kwon
Project Manager



David Chan
Mask Strategy



Bryan Rice
Director of Lithography

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